



# CAPTIVES OF THE SUN

*By James S. Pickering*

ASSISTANT ASTRONOMER, HAYDEN PLANETARIUM

WITH MORE THAN 125 HALFTONE AND  
LINE ILLUSTRATIONS

EVERY PLANET, moon, comet, asteroid and meteor within our solar system is a captive of the sun. And every man and other living thing that we know is part of this same captivity. With the cyclonic advance these days in space exploration, a knowledge of that captive solar system is imperative to understanding the exciting adventures of our time.

This book contains a unique discussion of the nature of space, whether between molecules or planets. Following chapters deal with the Earth, including a consideration of it as a typical pattern for other habitable planets. Similarly, the moon and the other solar planets are described in the light of the most recent scientific discoveries. Asteroids, meteors and comets follow in their course. *Captives of the Sun* thus becomes a complete, up-to-the minute presentation available for the student and general reader interested in the growing world of today and tomorrow.

The author is a staff lecturer at the famous American Museum-Hayden Planetarium in New York City and is author of the popular *1001 Questions Answered About Astronomy*.

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523.2 P59c 62-21977 \$4.95

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Captives of the sun. Illus.

with photos., and with drawings

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Dodd, Mead [1961]

326p. illus.

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# THE BOOK

## CAPTIVES OF THE SUN

Also by James S. Pickering

1001 QUESTIONS ANSWERED ABOUT ASTRONOMY

THE STARS ARE YOURS

# **Captives of the Sun**

**By James S. Pickering**

Assistant Astronomer, American Museum—Hayden Planetarium

ILLUSTRATED WITH PHOTOGRAPHS

AND WITH DRAWINGS BY JAMES MACDONALD

**Dodd, Mead & Company    New York**

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Library of Congress Catalog Card Number: 61-14115

Printed in the United States of America

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## CAPTIVES OF THE SUN



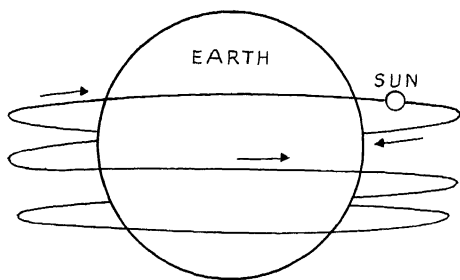
## The Oldest Science

IN THE BEGINNING, man's efforts to understand and interpret his surroundings were based upon what he saw—and man has always been too ready to believe his eyes. Look out-of-doors yourself and try to see what he saw in the light of his totally uneducated and primitive understanding. He lived upon the same Earth as you, and he saw it as you see it, but he took what he saw literally. The Earth to him was enormous beyond comprehension, stretching away on every side as far as he could see. Some of his fellow men knew from experience that if they went journeying, the Earth continued to spread out before them, growing as they traveled. Barring incidental unevennesses, the Earth was obviously flat. When a man chanced to have the ocean for his horizon or to be in the center of a level plain, the Earth was completely flat.

Over primitive man's head and over the Earth on which he lived there passed every day a bright, hot Sun. The Sun was not very large, perhaps as big as his head, but it was rather near him because he could feel its heat, and nothing in his experience could throw heat for any great distance. Perhaps some remembered conflagration, a lava flow from a volcano, might have cast its glow for a mile or so, but such things were obviously far bigger than the Sun, if not quite so bright. This small Sun swung about the Earth at regular intervals, moving rapidly across the sky. When man had watched it for

sufficient time, it did show certain changes of movement. There was a period each year when the Sun rose each day slightly farther to the south, and its journey across the sky became increasingly shorter. Man had been told, in folk tales that came to him from his ancestors, that there might come a day when this southward journey of the Sun would not stop, but would continue until the Sun would no longer rise and the Earth would be left to eternal cold and darkness.

Man of two thousand years ago could smile at this superstition—smile, but perhaps with a trace of ancient tribal misgiving still troubling him. Some genius had solved the



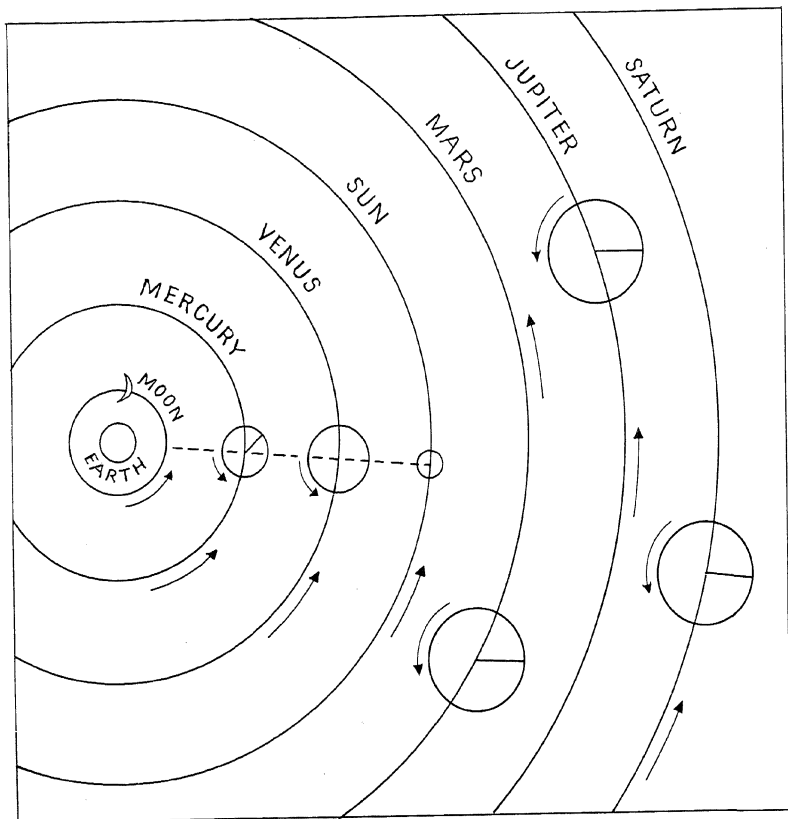
**The Sun moved up and down around the Earth through the year.**

problem. The Sun went around the Earth in a spiral path. It went around 182 times going downward, to the south, and then it reversed itself and went around another 182 times moving upward, to the north. That was history. The Sun had performed this same rite, cycle after cycle, and the time taken for the complete descent and ascent of the Sun was the year. The ancient fears of the Sun's complete disappearance were almost forgotten, but they were responsible for one pleasant event. Each time that the Sun began to climb back to the north, a festival was held, an ancient feast far older than anyone could calculate, which everyone enjoyed even though they all knew that the Sun would continue in its ordained path whether anyone celebrated or not.

Each night, after the Sun had disappeared below the far side of the Earth, the sky took on an entirely different appearance. First of all, there were the stars. These were, of course, tiny holes made in a great dark sphere that covered the Earth like a bowl. Through these tiny holes the light from an overlying bright hollow sphere shone and made the stars. This outermost sphere was the source not only of the light of the stars but of their motion and of the motion of the whole complicated system of spheres, for there was much more to this arrangement than the star sphere. The motion of the star sphere, imparted to it by the prime mover, the outer shell of light and motion, was such that the star sphere turned about the central Earth in one day. The star sphere also carried with it a number of other spheres, to which were attached various individual objects whose periods of revolution about the Earth were not the same as the period of the stars.

There were, of course, the Sun and the Moon, which had to have individual spheres because their motions were unlike. In addition to these two brightest objects, there were five stars that moved individually among the other stars, which were all fastened to the same star sphere and were fixed in that they could move only as a group.

The first of these five wandering stars, or planets, was fastened to the sphere next inside the star sphere. This sphere carried only one star, Saturn, and was moved about the Earth by the force imparted to it from the outermost sphere of light, the prime mover. Inside the sphere of Saturn moved the Jupiter sphere, which carried its planet about the Earth in twelve years. Then came the sphere of Mars, which moved Mars about the Earth in two years. The Sun was next, and its sphere carried it about the Earth in one year. Inside the sphere of the Sun turned the sphere of Venus, which moved much more slowly than did the Sun sphere, taking Venus about the Earth in eighteen months. Then came the sphere



**The Sun and the planets moved about the Earth on the circumferences of small circles whose centers traveled on the circumferences of large circles.**

of Mercury, moving about the Earth in three months. To the innermost sphere of all was attached the Moon, carried about the Earth in one month. At the center of this maze of concentric spheres stood the firm and enormous Earth.

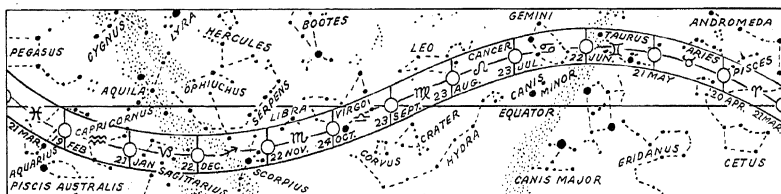
There were many puzzles in this system, and the ancient astronomers devoted much time and thought to their solution. Mars, Jupiter, and Saturn were seen to possess certain irregularities, which gradually became known after years had been

spent in observing and recording their motions. Each of these planets at varying intervals ceased its normal progress and moved backward, apparently traveling in loops now away from and now toward the Earth. After a time it became evident that this irregularity was regular, for Saturn passed through twenty-nine of these loops in its long journey about the Earth, and Jupiter accomplished twelve. This meant, of course, that there must be some more complicated arrangement than one sphere for each of the planets. There must be, rather, several spheres for each planet, and all the spheres affecting the motions of the same planet were turning upon the same axis, and this axis moved about the Earth on still another sphere. Aristotle finally solved the problem with a system that required eighty spheres. This was incredibly complicated, but it worked—the phenomenon was saved, and that was all that anyone could want. All of the planets moved about points on a larger sphere, and it was the larger sphere that moved about the Earth. This took care of the strange looping of the planets. Such was the amazingly complicated mechanical system of spheres within spheres and cycles within cycles by which the ancients tried to explain the varied and involved movements of the heavenly bodies.

As far as the Sun was concerned, its combination of motions about the Earth in a year and its swifter motion about the Earth in a day were also due to a similar system of cycles. One cycle took care of the daily motion, and the center of the daily cycle moved, in turn, upon the circumference of a second cycle called a deferent. This made the Sun move slowly and steadily before the stars of the night. It took many years for these conceptions to be formed. Man kept records of the motions and positions of the Sun, and from generation to generation bits and pieces of knowledge were passed down and put together in a sort of mosaic. There were no stars in the daytime, but just before the day began, stars could be seen moving around the Earth ahead of the Sun. These stars

told man that the stars immediately following them had to be beyond the Sun in the daytime, for he knew the order in which the tiny holes that he believed produced the stars were made in the star sphere.

In the first month of the year, named for Mars—not because he was the god of war but because, in an earlier conception, Mars had been the god of growth and spring—the Sun stood before the stars of Aries, the great ram whose golden fleece was the goal of the heroic adventures of the Argonauts under Jason. Almost each time that the Moon changed its shape, the Sun, moving in the opposite direction to that which it



**The constellations and signs of the zodiac. The signs commemorate the original positions of the Sun and are now one constellation behind the present position of the Sun.**

took in its quick daily circling of the Earth, had traveled far enough across the sky so that it was before the motionless stars of a different constellation. After Aries, for example, the Sun slid slowly before the stars of Taurus. The planets and the Moon moved, too, along a much wider path than did the Sun, and they remained within this wider path, shifting a little from side to side as they went, with the planets reversing their direction periodically for brief intervals. The wide path the planets followed, lying as it did over the path of the Sun, but extending farther out on either side, was always before the stars of twelve of the constellations. These twelve



made up the zodiac—the belt of living things. It was called the zodiac because all but one of the objects represented in these constellations were animate. The one exception was Libra, the Scale.

The twelve constellations in the order in which the Sun moved before them in the course of the year are, first, Aries, which has been explained. Then comes Taurus, the Bull, whose form Jupiter assumed when he abducted Europa. Next are Gemini, the Twins, Castor and Pollux, who are represented by two bright stars shining through the star sphere at this point. Castor and Pollux were the twin sons of Leda. Their father, Jupiter, visited Leda in the form of a swan. Castor was the first man ever to tame and ride a horse, and Pollux developed the art of striking with the fist and fending off the similar blows of an opponent.

The next constellation before which the Sun passes is Cancer, the Crab. This name represents a touch of humor. The Sun was before Cancer during the time its motion carried it most nearly overhead. It then turned and began to descend, going backward like a crab, and so the stars before which it began its turn are named for the crab. Leo, the Lion, is the name of the next constellation of the zodiac. Leo is very old. From remote times comes the legend that it was Leo and not Cancer before which the Sun stood when it had reached its greatest height in the sky. This fact made Leo the king of the constellations, and it was accordingly named for the king of the beasts.

After Leo, the Sun passed before the stars of Virgo, the Virgin. This was, of course, the Sun's position during the time of the year when growing things were ripe and ready to be harvested. Proserpine is the goddess of the harvests, and she is Virgo. Next comes Libra, the Scale. There seemed to be some doubt about the name of this constellation. In earlier times the stars of Libra were considered to be the claws of the Scorpion. They were later seen as separate and called

the Scale. Scorpius was the next host of the Sun. The arrangement of the stars of Scorpius does form the outline of this deadly little animal, but in the sky, Ophiuchus, the great giver of health, is treading on the Scorpion and will keep him under control.

Sagittarius, the Archer, lies behind the next portion of the Sun's path. Sagittarius was the beloved centaur Chiron, tutor and trainer of the gods. Chiron's greatest skill was his remarkable ability with the bow, and he is always remembered as an archer. Next to Sagittarius is Capricornus, the Horned Goat. All the world once believed that this part of the sky was the great Ocean Sea of Heaven and that Capricornus, who lived in this sea, was a fascinating creature, half goat and half fish. This was the ancient legend, but this was also the place at which the Sun began its long climb up the skies from the descent it began in Cancer. Nothing can climb as well as the goat, so the source of the name is obvious.

After Capricornus the Sun rides before the stars of Aquarius, who was cupbearer to Jupiter. Aquarius is most active during that part of the year when the Sun passes before him, for it is then that the annual rains fall from the skies. Last of the zodiac, completing the belt of animals, are the stars of Pisces, the Fishes. After the rains comes the time of good fishing, and here are the fishes to commemorate this time.

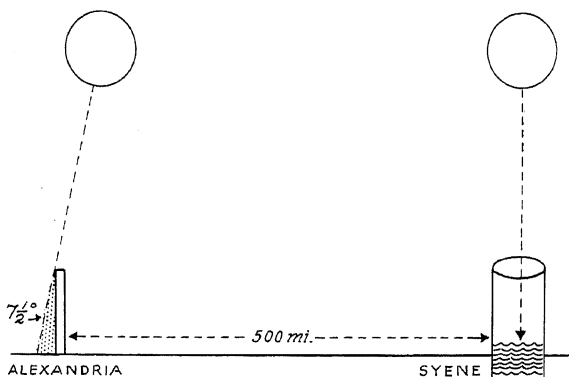
\* \* \*

This was the picture that the well-educated individual of almost two thousand years ago had of the universe. The order of position of the various objects was, first, Earth, motionless and enormous, the center of the universe. Then, moving on the surface of a crystal sphere that carried it around the Earth, was the Moon. Beyond the Moon, sliding around the circumference of a small circle, was Mercury. Then came Venus; then the Sun; then Mars, Jupiter, and

Saturn, and, finally, shining through holes in an outer sphere were the stars. These various concentric spheres were kept in motion about the Earth by one outermost sphere, the prime mover, from which also came the divine light that made the stars. These spheres slid together, rubbing against one another as they moved, and the friction of their sliding produced a sound that was sublime and all-pervading. Although man heard this sound, he was not conscious of it since it never ceased and since there was never silence with which to compare it. This sound, beautiful beyond all imagining, was the music of the spheres.

While this amazing structure was being built in the minds of early civilizations, certain individuals were attending to the various details of its construction. The outstanding accomplishment of the early investigators was perhaps that of Eratosthenes. He was born in 275 B.C. and was the director of the great library at Alexandria which had been established by Alexander the Great. Eratosthenes measured the circumference of the Earth by pure reason. There was in the city of Syene, considerably south of Alexandria, a well. On one day every year, the day on which the Sun reached the topmost point of its journey around the Earth, its rays penetrated to the bottom of this well. The Sun never stood directly overhead at Alexandria.

In Alexandria, Eratosthenes set up a gnomon, a small vertical pillar. On the same day on which the rays of the Sun struck the bottom of the well at Syene, Eratosthenes measured the angle of the shadow that this gnomon cast on the sands at Alexandria. He found that this angle was  $7\frac{1}{2}$  degrees from the vertical. Seven and a half degrees is 1 part in 48 of the circumference of a circle, which contains 360 degrees. Then Eratosthenes had surveyors measure very carefully the distance between Alexandria and Syene. The distance between the two cities was found to be 4,342 stades. The stade is 517 feet, so there were 510 modern miles between



**The Sun, directly overhead at Syene, was  $7\frac{1}{2}$  degrees from the vertical at Alexandria.**

Alexandria and Syene. If there was a difference of 1 part in 48 between the angle of the Sun at Alexandria and its angle at Syene, then the distance between these cities must be 1 part in 48 of the circumference of the Earth. Forty-eight times 510 miles is 24,500 miles—which is only about 50 miles from the present figure for the circumference of the Earth. This was a remarkable feat, but even more remarkable is the mental process by which it was accomplished, in that Eratosthenes conceived the Sun to be at such a great distance from the Earth that its rays could be considered parallel.

About fifty years later a young Greek from Nicaea saw a star in the sky in a place where no star had been visible before. The star was not new, but it had suddenly become visible by undergoing a metamorphosis that we often see but that is not yet fully understood. Some imbalance of the atomic structures of certain stars causes them suddenly to increase in brightness and temperature by many thousand-fold in a few nights, making a normally faint star bright enough to be seen for the first time and sometimes increasing its brightness by a factor of hundreds of thousands. Such stars, which are now familiar phenomena, were long considered to be new stars and were then, and still are, called by the Latin word for "new"—*nova*. The young Greek who saw this particular nova was Hipparchus, and its sudden appearance made him realize the need for a catalogue of stars in order that man might be aware of the stellar population and

thus be able to note any changes that might take place in the skies as stars were born or died. With infinite patience and arduous labor, Hipparchus located 1,080 stars, establishing their positions in relation to one another and classifying them by degrees of brightness.

Into his first category of brightness, Hipparchus put those stars that were very bright. Next came the stars that were merely bright, then those that were bright medium, and then the faint medium. Below these were the faint and, last, the very faint stars—the faintest stars the eye could perceive on a clear night. Hipparchus watched in the early mornings and saw that certain stars rose just before the Sun and that these stars were not always the same. He also checked those stars that appeared to the west as soon as dark set in after sunset and saw that they, too, were not always the same. Thus he located accurately the position of the Sun before the stars through the year. His work in this field gave him a measure of the length of the year that was within six minutes of the modern figure. He watched the Sun and the Moon and found that their apparent diameters changed from time to time. He had the imagination to realize that this change was not caused by the physical swelling or shrinking of these bodies, but that it was because they were at times nearer to and at other times farther away from the Earth. He even calculated that the Moon was, on the average, thirty-three Earth-diameters distant, which was wrong by only three Earth-diameters. He tried, but unsuccessfully, to measure the distance to the Sun by the size of the Earth's shadow upon the Moon during an eclipse of the Moon.

This meticulous labor of Hipparchus was not looked upon highly by his contemporaries. They felt, first of all, that it was blasphemous, for the whole business had been settled by Aristotle some centuries before. Everyone knew that these niggling details were ridiculous because the various heavenly bodies were spiritual, and not physical, and had all of man's



**Claudius Ptolemaeus**  
(fl. A.D. 140)

fate under their control. Anyone who thought that timing, size, and distance could be translated into earthly terms was also a bit stupid. What possible good could come from it? This attitude explains why, three hundred years later, Claudius Ptolemaeus had few other data to draw upon when he wrote the work that crystallized man's conception of the universe for about fifteen hundred years.

This tremendous work of Claudius Ptolemaeus—known to us as Ptolemy—is the earliest complete treatise on astronomy that has survived. It marks the transition of astronomy from speculation into science. Ptolemy called it *The Great Astronomical Syntax*, perhaps not so much because he thought highly of his own writing as because its scope was much wider than that of an existing work called *The Smaller Astronomical Syntax*. In this treatise Ptolemy included everything that he could find and of which he approved about astronomy. He leaned heavily upon Hipparchus for much that is sound in his book. He found out, in the writing, that he had to change the locations of the stars slightly from the positions

in the constellations that Hipparchus had given them, confirming Hipparchus' discovery of precession—the slow westward motion of the equinoxes along the sun's path through the sky—and he solidified the rather indefinite constellation boundaries that were somewhat informally understood before his time.

In Ptolemy's sky there were forty-eight constellations in which the most striking star formations were found. These constellations were not necessarily contiguous. Ptolemy's catalogue lists, in addition to the stars in the constellations, 108 bright stars that were isolated and were found in the spaces between the constellations. He also gave names to most of the prominent stars. These names were largely locational, such as the Right Shoulder of the Giant, the Forefoot of the Twin, and so on. He may have devised some of these names himself, and he certainly recorded many star names that had been traditional for years. In *The Great Syntax* he set down the whole system of his time, culled from the past, from records that he possessed or had examined. It is from this book that we get most of the concepts of Ptolemy's time and of the great astronomical pioneers who preceded him.

For centuries after Ptolemy the western world was in scientific darkness. In the seventh century after Christ the Arabs captured and burned Alexandria and its library but, for some reason, they spared Ptolemy's works. The Arabs admired them and adopted their Greek name, which may be transliterated as *Tes Megale Syntaxis tes Astronomias*. They elevated the Greek comparative *megale* to the superlative *megiste* and gave it the Arabian definite article *al*. Thus the book acquired its present name, *The Almagest*. For almost fifteen hundred years *The Almagest* was astronomy.

The Ptolemaic place names for the stars were translated literally by the Arabs and came back to western civilization

in Arabic, strangely altered in some cases, owing to the Moslems' repugnance to any portrayal of the human figure. Many of the ancient Arabian constellations were made up of flocks of sheep, goats, and camels instead of the individuals of the Greeks, reflecting thus the pastoral civilization of the Arabs. Ptolemy's Right Shoulder of the Giant was transmuted into the Armpit of the White-Belted Sheep, which is a translation of the name now used for the great red star in the northeastern corner of Orion. "Bet-el-geuse" is part of that Arabic name, which became a strange combination of Greek and Arabic. Deneb, a name borne in one form or another by half a dozen different stars, is the Arabic word for "The Tail." There are Deneb in Cygnus, the Swan; Deneb Algaedi, the Tail of the Goat in Capricornus; Denebola, the Lion's Tail in Leo, and so on.

A slight advance in astronomy was made by the Arabs after Ptolemy, notably by Ulugh Beg who catalogued the stars again, changing slightly some of Ptolemy's locations, as Ptolemy had found it necessary to change some of those of Hipparchus. Another famous Arabic suspect in astronomy is much better remembered for his verse, Omar Khayyam.

In any event the flame wavered and flickered, but it did not die. The strange wandering stars, the planets, were held in an inflated importance by that renegade relative of astronomy—astrology. The belief in the influence of the planets on the lives and fates of individuals, cities, and nations was common throughout most of the civilized world and, unfortunately, still remains strong in many eastern countries and, to a small extent, everywhere. Horoscopes were cast by men whose skill in locating the planets and in following their motions could have been devoted to a better purpose. It might almost be said that astronomy was kept alive by astrology, the black sheep of the family.

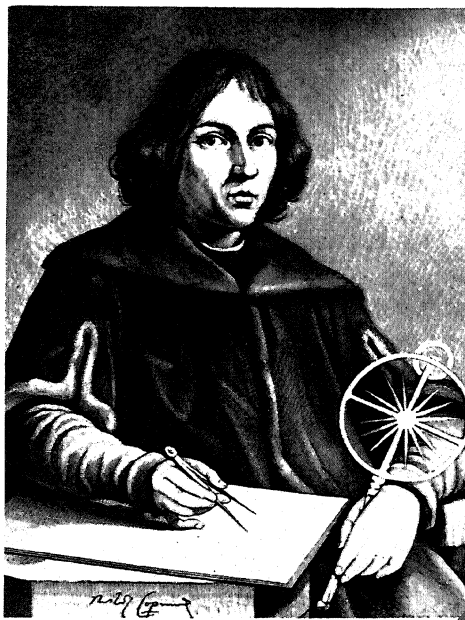
During all this time, in the minds of men the enormous central Earth remained motionless while around it, locked in



their musical spheres, moved the Sun, the Moon, the five visible planets, and the tiny, distant stars. Yet, all the while, the strange, looping motions of the planets, the small deviations of the Sun and the Moon from the rules that had been laid down for them by the ancients, plagued the real scholars.

A quiet, self-effacing Polish physician-priest spent many of his free moments in meditating upon these matters. From time to time he drew crude diagrams in which he attempted to demonstrate what he believed to be happening, and he finally succeeded in convincing himself of the correctness of his new conception. He wrote it all out and showed it to a few of his friends. The result was as he had feared it would be. His theory was scorned and mocked because it deprived man, proud man, of his position in the center of the universe. Nikolaus Kopernik, called Copernicus, had dared to say that the Earth—the limitless, motionless, central Earth, did not stand still in the middle of everything, but moved about the Sun, as did all the other planets. The apparent loops in the

**Nikolaus Copernicus**  
(1473-1543)



paths of the other planets were an illusion caused by the varying speeds at which the Earth and the other planets moved about the Sun and by the consequent varying angles and directions at which they were seen from the moving Earth. As the Earth passed a planet that was moving more slowly, its greater orbital speed made that planet appear to pause and retreat until the Earth was some distance ahead of it. Then it would resume its normal course and appear to move regularly again.

The picture drawn by Copernicus was very broad and general, and there were many details that he was unable to put into their proper relation. In the main, however, it did solve, in a fairly simple manner, motions that had completely baffled men up to that time. Ultimately Copernicus was persuaded by his friends and by no less an authority than the Church of Rome to continue his work. He did, with great misgivings about its possible reception. He withheld the publication of his book, which he called *De Revolutionibus Orbium Celestium* (*Concerning the Revolution of the Celestial Bodies*), until his own last days, and a copy of it was put into his dying hands in 1543. For two hundred years man eyed it with skepticism; and it is recorded that in the early days of such institutions as Harvard and Yale, students were cautioned to regard the ideas of Copernicus as hypotheses and not as established facts.

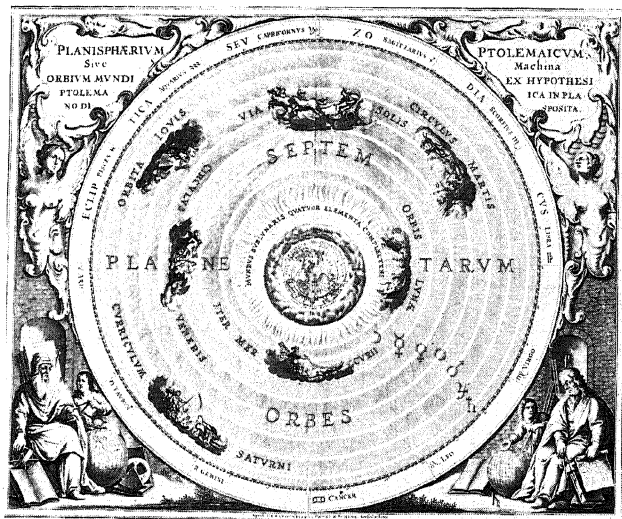
On November 11, 1572, a star appeared where no star had ever been seen before—another nova, flaring up at the psychological moment. It increased swiftly in brightness until it became the third brightest object in the skies. It could be seen by day, and it cast shadows at night. Its appearance and its progress during its life of about eighteen months were watched and recorded by an irascible, egotistical Danish genius named Tycho Brahe, whom astronomy had already strongly tugged away from his elected fields of law and chemistry. Tycho published an account of this star which



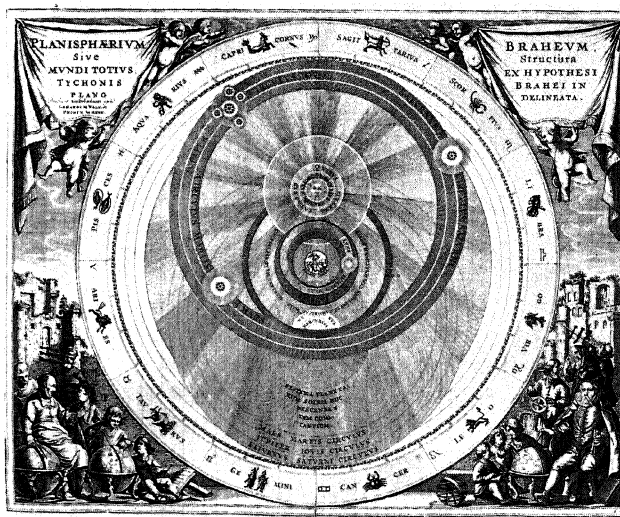
**Tycho Brahe (1546-1601)**

made him famous and steered him into his life's work. He lectured and fought and argued and was given the equivalent of a Mount Palomar by his king, Frederick II of Denmark. This was Uraniborg, an observatory on the island of Hveen in the Sound north of Denmark. Tycho equipped his observatory with the finest instruments he could buy or make, and embarked upon a meticulously accurate observation of the sky. He plotted the positions of the planets almost hourly. He devised methods of averaging his observations to eliminate error. He quarreled with the wrong people and was finally tossed unceremoniously out of his ivory tower and came to rest in Austria, where he died within a few months.

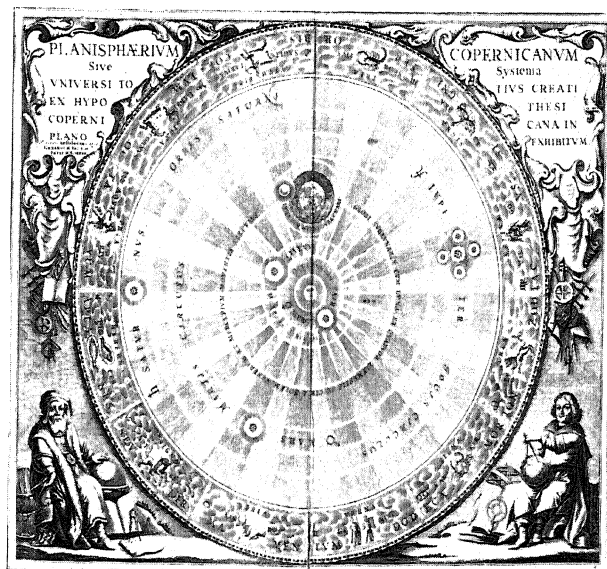
Tycho disagreed violently with Copernicus. He declared that the Sun moved around the Earth and that the other planets moved around the Sun. He left the stars in the position most distant from the Earth and produced a star catalogue of his own. Unwittingly, in his uncannily accurate observations he left the ammunition that was to destroy his own theory and confirm the general idea of that of Coper-



**Geocentric system according to Ptolemy.**



**Tycho Brahe believed that Mercury and Venus revolved about the Sun, which revolved about the Earth. Mars, Jupiter, and Saturn revolved directly about the Earth.**



**The Copernican System, in which all the planets move in circles about the Sun.**

nicus. He willed his priceless figures and notes to his German pupil and assistant, Johannes Kepler, with instructions that they be used to refute the Polish upstart.

Johannes Kepler set out to do exactly as his master and patron had commanded, but several other projects in which he was engaged had priority. Kepler had come to Tycho after a varied career which started with a miserable and poverty-stricken boyhood filled with sickness and trouble. His father deserted his family, and his mother, in her declining years, was persecuted as a witch. Kepler had, in spite of these tribulations, a flaming genius and an inner drive that hurled him through all obstacles. He joined Tycho in Austria the year before Tycho's death, having left a precarious post in the University of Tübingen to do so. Kepler was convinced in his own mind of the essential correctness of Copernicus' theory, but he agreed with Tycho that it needed proof, although he did not adopt Tycho's strenuous and



**Johannes Kepler**  
(1571-1630)

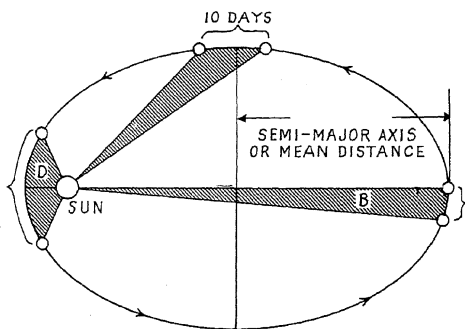
belligerent objection to it.

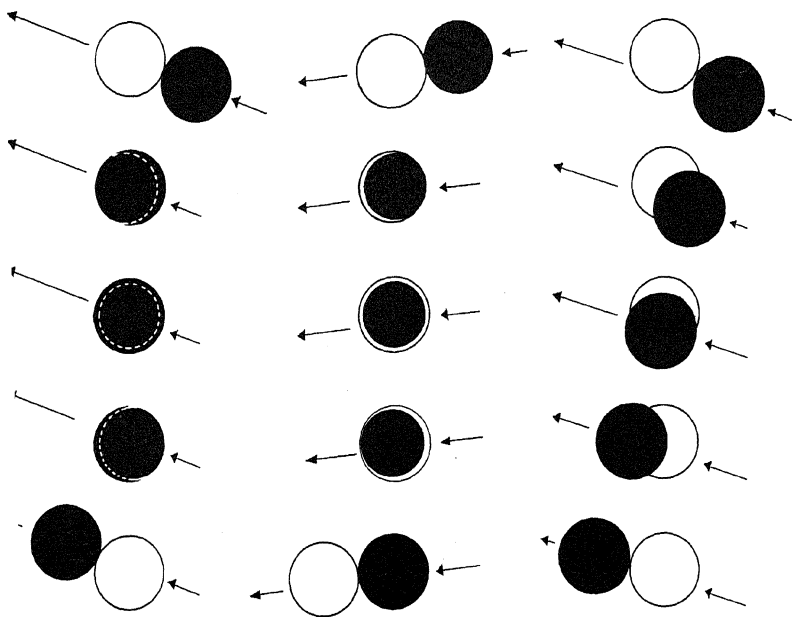
To keep himself alive while he was preparing to investigate these matters, Kepler completed the lunar tables that he and Tycho had begun for the Emperor Rudolph, and turned his hand, when the idiosyncrasies of his patron demanded it, to the casting of horoscopes and the ambiguous prediction of coming events. In his spare moments he examined Tycho's voluminous data on the planets. He found that the figures on Mercury had many gaps caused by Mercury's periodic disappearance either beyond the Sun or while passing in front of it. He found that Venus, too, suffered from these deficiencies, although not as frequently as did Mercury. The figures for Jupiter and Saturn indicated so little change over many years that Kepler could see his own demise arriving before he could collect enough supplementary information to draw a sound conclusion about these two planets. Mars, however, was different. Mars moved much more rapidly than Jupiter or Saturn and spent only a few days every two years in conjunction with the Sun. Mars also showed far greater

eccentricity in its wanderings than did any of the other known planets.

Kepler labored for nine years, trying and discarding, building up and tearing down theory after theory. Copernicus had drawn a picture in which the planets moved in circles about the Sun. The circle was the most economical, the perfect mathematical figure, and yet Mars could not move in a circle. Tycho's figures, checked from time to time by Kepler himself as they were being collected, showed a wide divergence from the circular and revealed a change of pace on the part of Mars that was indisputable. At last the solution came after what must have been the most frustrating, back-breaking kind of work. Mars moved in an ellipse. Kepler also found and formulated the law that explained the apparent speeding up and slowing down of Mars. Because the planet moved in an ellipse, its distance from the Sun was constantly changing, for the Sun occupied one focus of the ellipse and nothing whatever was at the other focus. When Mars was at its greatest distance from the Sun, it moved much more slowly than it did when it was at its least distance from the Sun. The formula for the relationship between velocity and distance at last came to Kepler. If a line were drawn from Mars to the Sun, this line would move over the same area of the plane of Mars's orbit in the same period of time, regardless of distance. Then, if Mars is near the Sun, its motion along its orbit must be more rapid than when it is farther away so that this line

**Kepler's Law of Equal Areas.** The radius vector sweeps out equal areas of the plane of the elliptical orbit in equal times. Area B, in which the radius vector is long, can be covered by a short travel. In Area D, the planet must move farther and hence faster to cover the same area.





**The mechanics of eclipses. (See page 75.)**

may cover the same area in the same time in any positions of Mars and the Sun.

The ellipticity of orbits and the law of equal areas were two of the three fundamental laws of planetary motion that Kepler discovered. So far from refuting the system of Copernicus, they confirmed the great basic principle of the Copernican theory—that all of the planets revolved about the Sun. Meanwhile, another great nova had appeared in the sky—a star comparable to that whose appearance had started Tycho on astronomical paths in 1572. In 1604 a supernova of almost the same brightness as Tycho's star appeared in the constellation of Ophiuchus. Kepler dropped everything to observe it and make voluminous notes upon it, so that it is still known as Kepler's Star. He kept at his chosen task, however, sure that there were still other relationships that would serve to confirm and stabilize the planetary picture. In 1610 a correspondent of his, an Italian, sent him a new toy. Galileo



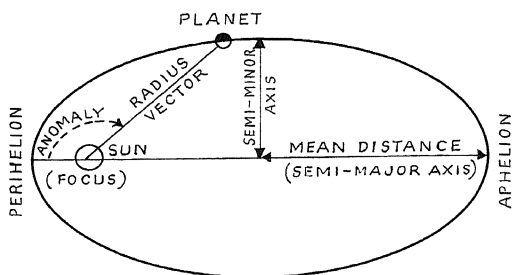
Galilei, who had been making telescopes for several months, gave one of them to Kepler, who was delighted and wrote a treatise on the theory of refraction by lenses, suggesting the principle of the inverting telescope. Another factor that made Kepler's task less arduous was the invention of logarithms by the Scottish mathematician John Napier. Kepler corresponded with Napier and made use of logarithms in his work.

In 1619, having undergone the sorrow of the deaths of his wife and his favorite daughter, having saved his mother from execution for witchcraft, having struggled for weary years with masses of figures, Kepler finally hit upon his third great law of planetary motion, the harmonic law. He found the relation between the length of time required by a planet to make one revolution about the Sun and the distance of that planet from the Sun: the square of the period (the time of revolution) is proportional to the cube of the distance.

Kepler himself realized that he had come upon something of supreme importance. His delight and his relief were unbounded. He literally shouted his exultation in his writing. "Nothing holds me," he said. "I will indulge my sacred fury; I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build up a tabernacle for my God far away from the confines of Egypt. If you forgive me, I rejoice; if you are angry, I can bear it; the die is cast, the book is written to be read now or by posterity, I care not which; it may well wait a century for a reader as God has waited six thousand years for an observer."

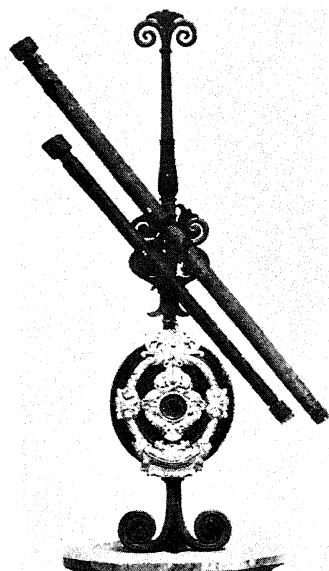
Kepler's laws hold not only for planets about the Sun but for any bodies in space moving about one another. All orbits are ellipses; all radius vectors sweep over equal areas in equal times; and the squares of all periods are proportional to the cubes of all distances for planets, for comets, for double stars.

While Kepler was struggling with his tremendous prob-



**The elements of an elliptical orbit.**

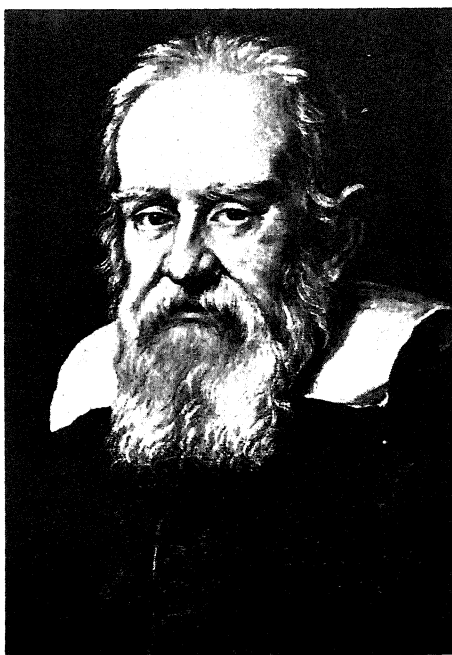
lems, his Italian friend was making no less important discoveries with his newly found optic tube. No one knows for certain who invented the telescope. The credit is generally given to a resident of the Lowlands, an oculist and spectacle maker named Hans Lippershey. At any rate, the principle of the instrument was suggested to Galileo by correspondence with a French nobleman, Jacques Badovere, and the legend goes that he knew enough about optics to build a telescope of his own in a day or two. His first telescope magnified about three times. During his life he built hundreds of telescopes and managed to increase their power of magnification up to more than thirty diameters.



**Two of Galileo's early telescopes.**

With this new instrument, somewhat less powerful than half of a modern field glass, Galileo pushed back the frontiers of astronomy many millions of miles. He saw the Moon and found that it was another world and not a sublime, phosphorescent body; he saw the Milky Way and translated that luminous cloud into countless billions of distant stars; he saw the planet Venus and found that it went through phases very much as does the Moon, thus confirming the soundness of the Copernican system; he saw that Jupiter had a family of satellites revolving around it and thus clinched Copernicus' picture still more firmly. Galileo's promulgation of his findings and their significance made his life stormy and exciting, and his observations of the Sun undoubtedly led to his ultimate blindness. He was born in 1564, the same year as Shakespeare, he was visited by John Milton, and he died in 1642, the year Isaac Newton was born. His work spans the gap between medieval and modern astronomy, and his tre-

**Galileo Galilei**  
(1564-1642)





**Isaac Newton**  
**(1642-1727)**

mendous spirit made him the best possible “first observer of wondrous things.”

Both Kepler and Galileo were on the brink of discovering why it was that objects in space behaved as they did. Both of them found out how, but neither quite succeeded in finding out why. Forty-five years after Galileo died, Isaac Newton, impelled by a strange and wonderful set of circumstances, published a treatise called *Philosophiae Naturalibus Principia Mathematica*. This contained the laws that have since become known as the laws of motion and gravity. These laws explained the behavior of the planets—and of all other bodies moving in space. To this day, although Newton’s principles have undergone some revision in extreme cases, his laws of motion and gravity are obeyed by those bodies that we are able to observe, and by man’s latest messengers into space, the artificial satellites, and, as amended by Einstein, will probably serve as the basis for all that man will be able to study of space for some generations to come.

With the work of Newton, man was in possession of the most important principles of the behavior of objects in space.

It was still necessary to analyze the physical makeup of these objects, to find out why they were bright or dim or irregularly brilliant, and gradually to probe into the nature of the planets, the stars, and the many mysterious clouds, both bright and dark, that seemed to lie among the stars. Many great men had a part in this exploration. Within the last fifty years man has made greater progress in astronomy than in all the ages that have gone before. New instruments, new and ingenious methods of using old instruments, are giving man improved glimpses into the depths of space—depths that we now know are immense beyond all imagining, filled with forces and elements that we are beginning to understand only dimly.

## The Earth in Space

### WHAT IS SPACE?

According to the dictionary, space is that which is characterized by extension in all directions; boundlessness and indefinite divisibility; the subject of determinations of position and direction. In addition to this official definition, there are several others. Space is the region between objects; the void through which a given body must pass before striking a second body. One of the best definitions of space has been given by Dr. James Van Allen, of Iowa State University. Dr. Van Allen analyzed the findings of some of the earliest artificial satellites sent into orbit about the Earth and was the discoverer of the two belts of radiation that surround the Earth in space. He said, "Space is that in which everything else is. Space is the hole that we are in."

For better or for worse, let that be it. Space is the region that contains the universe. According to the definition of universe, there can be nothing else in space and certainly nothing outside it. We live in space on a tiny, moving, spherical island. We are preparing at the moment to push away from that tiny island into the three-dimensional void in which it floats.

It is essential that we disabuse ourselves of the association of emptiness with space. "Empty" has become a Homeric epithet for space, but the emptiness of space is a myth. With

proper investigative instruments there is probably no such condition as empty space. If we were able to magnify sufficiently, we should probably find that any given volume of what we call empty space would be as filled with odds and ends as is a drop of apparently clear water when viewed through a microscope. All but a tiny fraction of the matter in space is invisible to us, because of either minuteness or distance.

If we were to imagine the universe reduced to the volume of the biggest enclosed space we can think of—something like Madison Square Garden in New York City—and if by some magic we were able to look through a window into this enormous room—which would contain, of course, all the matter that the universe now contains, reduced proportionately—it would be empty as far as our senses could tell. It would be far more empty, if a comparative form of that word is permissible, than any comparable space we could visualize. No magnifying instrument we could possibly devise would reveal anything to us.

If we were to enlarge this room until it was the size of the Earth—a hollow sphere 8,000 miles in diameter—we might be able to see a few tiny, almost indistinguishable specks floating in it, as motes of dust float in a beam of sunlight. There would, however, be far fewer such specks than the motes of dust we might see in the most meticulously kept room.

If we increase the dimensions of our room until it becomes the universe, the dimensions of these specks will increase until each of them becomes a galaxy made up of billions of stars, threaded with clouds of gas and dust. We can begin to see now where the association of emptiness with space began. In spite of the theoretical crowded condition of space, Edwin Hubble, one of the world's great astronomers, has estimated that the proportion of matter to space can be expressed by the mathematical notation  $10^{-21}$ . This is shorthand for either the decimal 0.000000000000000000001 or the fraction

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It has always been difficult for man to imagine such a state of relative emptiness. It would have been easier perhaps if the distribution of matter in space had been uniform, as it may once have been. One great writer on such matters, Sir James Jeans, has said: "The picture of creation calls for a scene in which all matter, in its most primitive form, is distributed evenly, homogeneously, throughout all space. Everything is in perfect balance, silent, dark, without motion. Evolution can begin only when motion is introduced. What gave it motion and, therefore, life? It was stirred by the finger of God."

Our ancestors had an aversion to emptiness. They tried to transfer this aversion to the natural state of things by proclaiming that nature abhors a vacuum. Actually nature contains far more complete vacuums than man will ever be able to produce artificially. In his earliest attempts to construct a model of the universe, man gave no thought to any conception that did not fill all of the region he imagined with something—the air he breathed or a similar substance. That anything could remain stationary or move without something tangible to support it or propel it was inconceivable. The heat and light from the Sun and the other stars must have a substance through which it could travel, as air is needed to carry sound. Something had to support the planets, even though Isaac Newton said that they were all moving and held in place by a mysterious invisible force which he called gravity, and that all things were constantly falling. This was so obviously impossible that ether was invented—ether, an all-pervading, invisible medium which not only upheld the Sun, the Moon, the planets, and the stars but also furnished the substance through which light, electricity, magnetism, and gravity could be propagated. Newton himself endeavored to account for gravity by postulating a difference of pressure



in the ether. Ether endured until about seventy-five years ago, when it seems to have faded quietly away. Emptiness, or relative emptiness, returned, and man finally accepted the idea of space.

Today man is poised upon the threshold of an awesome region. He is certain, for the present at least, that it contains a completely incomprehensible number of objects of all natures and sizes. He is convinced of his ability to make journeys for relatively short distances to a few of the nearer of these objects, but he is, and with good reason, dubious about the possibility of more ambitious voyages. Somewhere in this region man lives. He is not completely certain of the location of his dwelling place in relation to the entire realm of space, although he has a fairly definite idea of its immediate surroundings.

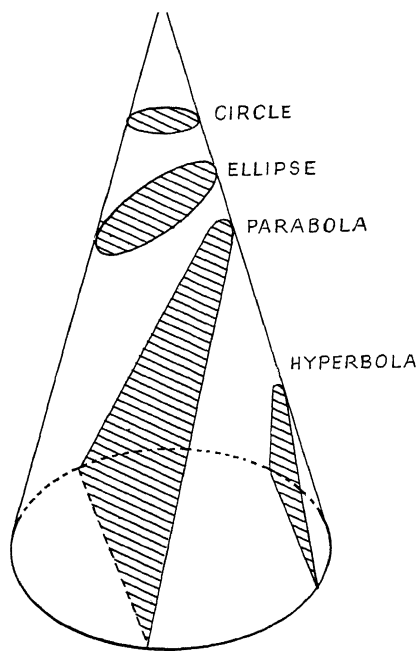
Man lives upon a planet that he calls the Earth, and to perhaps half of its inhabitants, the Earth is spherical. The other 50 per cent either do not care one way or the other or still continue to regard the Earth as flat.

It is extremely difficult to prove that the Earth is spherical. To be sure, it does cast into space a shadow with a curved edge. This shadow can be seen occasionally upon the surface of the Moon during a lunar eclipse, but a curved shadow could also be cast by an object that was flat but circular in cross-section—a disk. The changing appearance of a ship traveling over the surface of the Earth, either approaching or leaving the observer, is perhaps the surest proof of the Earth's shape. The emergence of such a ship above the horizon as it approaches—or its gradual disappearance below the horizon as it leaves—is vastly different from the same approach or departure over a flat plane. Finally, photographs taken of the Earth from great heights by research rockets show an indisputable curve to its surface, which confirms its sphericity.

Since the establishment of our present conception of the solar system, we are fairly sure that the Earth is the third

planet in order of distance from the Sun. The presence of a fourth planet, which was tentatively named Vulcan, between the Sun and Mercury was suspected for some time, but search has failed to find it, and reason has finally eliminated the possibility of its existence. Man has been able to measure the distance between the Earth and the Sun with reasonable accuracy, but he is still constantly trying to refine that measurement, and he has changed it from time to time as he convinced himself that he had reached a more accurate estimate. The latest figures run from a few miles less to a few miles more than 93,000,000. For the sake of convenience, let us call it 93,000,000 miles. This is the mean distance from the Earth to the Sun—the mean between two extremes—for the Earth, like all the planets, moves about the Sun in an ellipse rather than in a circle.

An ellipse is one of the most difficult figures either to explain or to draw. Even the dictionary has trouble defining an ellipse, but we must admit that the dictionary definition is probably the best one. Here it is: "An ellipse is the path of a point that moves so that the sum of its distances from two fixed points (called foci) is constant." Perhaps it would be easier to picture an ellipse by using conic sections. A cone is a solid whose base is a circle and whose sides taper constantly and evenly to a point. If we cut through a cone on a line parallel to its base, the figure we have when we lift the two pieces of the cone apart is a circle. If we cut through the cone on a line that is not parallel to the base but that nevertheless cuts through both sides of the cone, the cutting, or section, is an ellipse. A circle is a form of ellipse. One of the two points, or foci, of the ellipse that the orbit of the Earth describes in space is occupied by the Sun. The other focus is empty, but it is there and can be definitely located. This same situation holds true, incidentally, for all the planets and for the asteroids, the comets, and the meteoroids while they are moving under the influence of the Sun and not under the



### Conic sections.

primary attraction of one of the planets.

In an ellipse it is obvious that a portion of the curve is nearer to one of the foci at a given time than it is to the other. So, as the Earth moves about the Sun, it is nearer to the Sun at one part of its journey and farther from it at another. This happens on every revolution. The journey that the Earth takes about the Sun consumes the period of time that we call a year. The Earth reaches its nearest point to the Sun at about the same time every year, early in January, during the northern hemisphere's winter and the southern hemisphere's summer. The difference between the Earth's closest approach to the Sun and its greatest removal is not large—about 3,000,000 miles, or a little more than 3 per cent of the mean distance between the Earth and the Sun. We are farthest from the Sun early in July of each year. Astronomy has special names for these two critical points in planetary orbits. The nearest approach to the Sun by a planet or, indeed, by any object that moves around it is perihelion. The word

comes from the Greek, as do many astronomical words, and is made up of the prefix *peri*, "near," and *helios*, "Sun." The greatest distance from the Sun is aphelion, from *apo*, "far," and *helios*.

The farther an ellipse is from being a circle, the greater is its eccentricity. The measure of the eccentricity of an ellipse is the ratio of one half of the longer axis of the ellipse to the distance between one focus of the ellipse and its center. In a circle, since both foci would be at the center, this ratio would be 1. In any other ellipse the ratio is a fraction of 1 and is usually expressed decimally. The eccentricity of the Earth's orbit, for example, is 0.017. The Earth ranks third among the major planets in having a nearly circular orbit. The eccentricity of the orbit of Venus is the smallest of all the planets, 0.007, and that of Neptune comes second, 0.009. Pluto has the most elliptical orbit with an eccentricity of 0.249.

The Earth's year is made up of an uneven number of days. There are 365 days 5 hours 48 minutes 46 seconds in the year we are talking about—the tropical year, the year of the seasons. This is the time taken by the Earth to complete one of its many motions—one of its three principal motions that are important to us. As can be easily seen, the number of days in the year is not divisible evenly into weeks or, in fact, into any of the periods of time taken by any of the other natural cycles of the Earth. This circumstance has kept man in a dither, as far as timekeeping is concerned, ever since he became aware of time. During its year the Earth travels about the Sun and returns to the same relationship with the Sun from which it started. It has come close to the Sun and moved away from the Sun, and all mankind is a year older at the end of that journey.

For some reason that we do not know, the Earth's path about the Sun is not in the same plane as the Earth's equator. If it were, life would be much more simple and much more

monotonous for all of us. The plane of the Earth's orbit is at an angle of 23 degrees 26 minutes 45 seconds to the plane of the equator because the Earth's axis of rotation is tilted. This means that the ecliptic—the name for the orbit of the Earth around the Sun—is more than a quarter of the way toward the poles from the equator at the points of its greatest departure from the equator.

Degrees, minutes, and seconds of arc are the divisions of the circumference of a circle. There are 360 degrees in every circle, no matter how big or how small it is. Each degree is divided into 60 minutes, and each minute into 60 seconds. These minutes and seconds have nothing whatever to do with minutes and seconds of time and are not to be confused with them. These minutes are derived from the word "minute" meaning "small." They get their names from an old method of breaking the degree into primary minute divisions and secondary minute divisions. Thus, the primary divisions came to be called minutes, and the secondary divisions became seconds, from "secondary." The number of inches, feet, miles, or light-years in a degree depends upon how big the circumference of the circle is. If you drew a circle on a piece of paper on your desk, the length of a degree or minute or second would be very small. If you look at a star, thousands of light-years away, the circumference of the imaginary circle upon which it is located and at whose center you are, is enormous; but it still has only 360 degrees. Each degree in this great circle, however, would be light-years in length.

The Earth, then, is tipped away from the plane of its orbit about the Sun by an angle of  $23\frac{1}{2}$  degrees, in round figures. This tip, or inclination of the Earth's axis, is nearly constant both in amount and in direction. We know that the north pole of the Earth points toward the North Star winter and summer, every night of the year. As the Earth moves around the Sun—as it revolves—it must constantly change its position relative to the Sun. If the north pole of the Earth is tipped

toward the North Star, and the position of that star in the northern winter is on the same side of the Sun that the Earth reaches in winter, then the north pole of the Earth must consequently be tipped away from the Sun. Those of us who live north of the equator are then, in a sense, looking down at the Sun, which is low in the sky and is hidden much of the time by the bulge of the Earth. We do not get as much benefit from the Sun in winter for this reason. The rays of the Sun that bring light and heat to the Earth reach the northern half of the Earth at a small angle to the equator. Because of the low position of the Sun our days are short and our nights are long and it is cold. At the same time the southern half of the Earth is benefiting, for the south pole is tipped toward the Sun. The Sun is high in the southern sky, shining more directly upon the surface of the Earth and giving the southern hemisphere long days and short nights. It is summer there.

In the northern summer the point at which the north pole of the Earth is aimed is beyond the Sun from the Earth so that the north pole is tipped toward the Sun—not because the Earth has changed its inclination but because the Earth has moved, completing half of its revolution about the Sun, and is on the opposite side of the Sun from where it started. Then the northern hemisphere is tilted toward the Sun, the Sun is high in the northern sky, northern days are long, and northern nights are short, and it is summer there. The southern hemisphere is having winter.

If the Earth's axis were not inclined thus to the plane of its orbit about the Sun, there would be no seasons. Each latitude would have a generally stable temperature and a constant length of days and nights. The equator would be hotter than it now is perhaps, and if cold weather were desired, it would be necessary to go nearer to either of the poles to get it. There would probably be much more of a vacation migration on the Earth than there is now, with

people going poleward in search of cooler weather or toward the equator if they wished for more warmth. The middle latitudes would probably have a climate all the year round similar to the climate that prevails in them during the equinoxes, in March-April and in September-October, and the Sun would rise and set at the same time all the year round in any given locality.

The inclination of the Earth's axis should intensify the effect of the varying position of the Earth through the year upon our climate. The Earth reaches aphelion early in July, just as the southern winter has swung into its stride, and it arrives at perihelion in January, when the southern summer has well begun. This would seem to make for severe winters in the southern hemisphere and very hot summers, but there is a mitigating factor. Far more of the surface of the southern hemisphere is covered with water than of the northern hemisphere, which has about an equal distribution of land and water. Water is the great leveler of temperature. It is reluctant to become either cold or hot, and its presence in the southern hemisphere prevents both winter and summer from being as extreme as they might be if there were more dry land there. As it is, Antarctica is one of the coldest and most desolate regions on Earth. In 1959 the coldest temperatures ever recorded on Earth were found there—in the neighborhood of 120 degrees below zero Fahrenheit.

The first of the three major motions of the Earth is, then, its revolution about the Sun. The second is its rotation, which gives us day and night. The Earth turns completely around on its axis in a period of time that we call a day and have arbitrarily divided into hours, minutes, and seconds. The direction of the Earth's rotation is from west to east, and everything on the surface of the Earth is carried around by that motion. As a consequence, everything in space appears to move in the opposite direction, from east to west, although the actual movement lies in the Earth and not in

the Sun, Moon, planets, and stars, which only seem to move. Man has always said that the Sun rises in the east and sets in the west. This is a convenient sentence, but there is just one little thing wrong with it. Not one word is true. The Sun does not rise and it does not set. What really happens is that the horizon of any given place on Earth moves constantly eastward or downward as we watch it, and that motion permits us to see, successively, objects that were hidden below it. Similarly, the western horizon moves up and over, successively hiding those things that we had been able to see. Thus, the Sun in the morning is uncovered by the eastward turning of the Earth, and in the evening it is hidden by the same motion, which has also made it appear to move slowly across the sky through the day from east to west. The stars and the planets are affected in the same way. We can see them, after the western horizon has moved up to cover the Sun and has thrown us into the great cone of shadow that we call night, apparently moving across the sky from east to west, like the Sun.

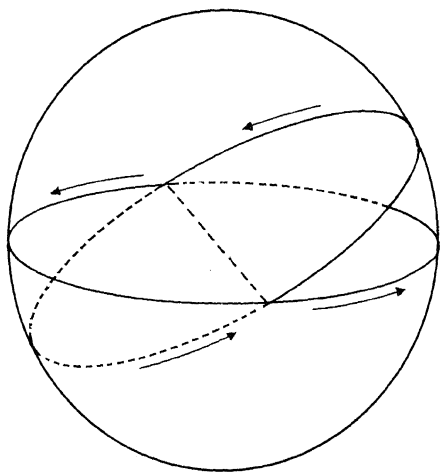
The precise direction of the motion of celestial objects, apart from being generally from east to west, depends upon the location of the observer on the Earth. At the equator, for example, the apparent daily motion of the Sun is at right angles to the horizon, as is the apparent daily motion of the planets and the stars. The astronomical name for the visible sky is the star sphere, harking back to the old belief that the stars were fastened to the inside of a vast black hemisphere which arched over the Earth. The star sphere as seen from the equator is called the right sphere because the Sun and the stars appear to rise and set here at right angles to the horizon. In the middle latitudes, either north or south of the equator, the direction of the Sun at rising and at setting changes with the seasons, but it is always at an angle smaller than 90 degrees to the horizon. The Sun and the stars appear to move obliquely up from the eastern horizon,



to slant across the sky, and to set obliquely at the western horizon. The star sphere in the middle latitudes is therefore called the oblique sphere. At the poles the stars neither rise nor set but circle completely around above, and parallel to, the horizon in a day and a night. At the north pole the direction of their circling is counterclockwise, and at the south pole, clockwise. The star sphere seen at the poles of the Earth is called the parallel sphere.

As we watch the sky from the Earth, the apparent motion of the stars varies with our location. If we are at the poles, none of the stars either rises or sets. In the middle latitudes we can also see stars that never rise or set but circle constantly, always remaining above the horizon. These stars are in large circular regions around the poles, centered upon the extensions of the poles of the Earth into space. In the case of the north pole, this extension passes within 1 degree of arc of the North Star, Polaris. At the south pole there is no "South Star." The south celestial pole falls into one of the most deserted regions of the sky as far as visible stars are concerned. These two areas around the celestial poles are the circumpolar regions. Their respective radii depend upon how far north or south of the equator the observer happens to be. If he is, for example, at latitude  $40^\circ$  either north or south, the radius of the region about the poles where the stars neither rise nor set will be 40 degrees of arc. In this region the stars will always be visible, either in that part of the sky most nearly overhead or in the sky between the celestial pole and the northern, or southern, horizon. Such stars are called circumpolar stars. To the observer at either pole, all of the stars are circumpolar, and at times the Sun and the planets seen there will be circumpolar, too.

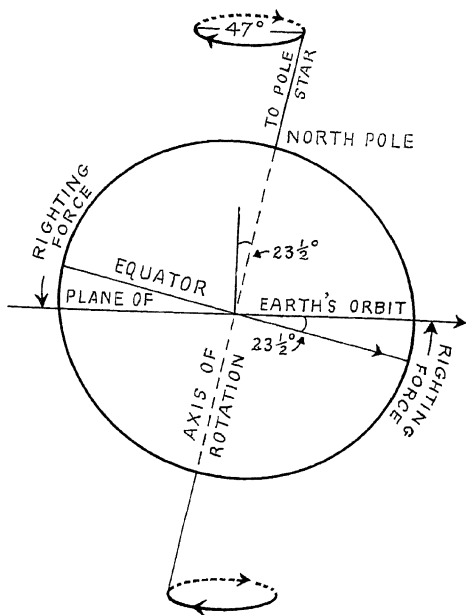
There is a third motion of the Earth that should be discussed here because it affects man's life and the appearance of the star sphere, although it is slow and scarcely noticeable. This motion is the precession of the equinoxes. First of all,



**The nodes of the Earth's orbit are the points at which the plane of the orbit crosses the plane of the equator.**

the equinoxes are those points in the star sphere at which the plane of the Earth's orbit about the Sun cuts the plane of the Earth's equator. There are two equinoxes because the celestial equator, an extension of the Earth's equator out into space, must intercept the ecliptic in two places. One of the equinoxes is the vernal equinox, and it marks the point where the apparent annual motion of the Sun, caused by the real annual motion of the Earth about the Sun, cuts across the equator when the Sun appears to be moving northward during the winter because of the inclination of the Earth's axis. When the Sun appears to reach this point in the sky, spring begins, on or about the twenty-first of March. The autumnal equinox occurs in September when the Sun appears to cross the celestial equator on the way south for the northern winter.

The Earth's orbit about the Sun is called the ecliptic because eclipses can occur only when the Sun and the Moon are on or near the plane of the ecliptic and in the same direction from the Earth. The equinoxes are definite directions upon the star sphere and can be located with great precision. They were first found ages ago and have been used as reference points for thousands of years. The vernal equinox marks the starting point for the measurement of all longitudinal



**The dimensions of the precession of the equinoxes.**

distances on the star sphere just as Greenwich, England—or the meridian of longitude that passes through Greenwich—marks the starting point for east and west terrestrial measurements. On the star sphere, however, astronomical measurements are always made to the east and never to the west. This eastward measurement is called right ascension. The circumference of the star sphere is divided into hours, minutes, and seconds of time, since the Earth turns completely within the star sphere in twenty-four hours. The vernal equinox is labeled either zero or 24. The convention of dividing right ascension into degrees, minutes, and seconds of arc is also used, but the imaginary lines that mark this division on star charts are always called hour lines of right ascension.

Distance north or south of the celestial equator follows the pattern of terrestrial measurements. The celestial poles, which lie in space directly above the poles of the Earth, are 90 degrees north and south of the celestial equator, which, of course, lies directly above the terrestrial equator. The divisions of measurement north and south on the star sphere

are in degrees, minutes, and seconds of arc, and this system is called declination, instead of latitude. The degrees north of the celestial equator are considered as plus and those south of it as minus.

The Earth is not a perfect sphere. It is slightly flattened at the poles, probably because of its plastic condition a few billions of years ago when it was young. At that time it was rotating much more rapidly than it is now, and more of its material was forced into a belt around its equator than was left in the polar regions. There is a difference of about 27 miles between the polar and equatorial diameters of the Earth. Because the Sun and the Moon are not constantly above the equator, they pull gravitationally at this belt of excess material. They try to force the Earth into a more upright position. The Earth, however, is spinning, and its spin has an effect similar to that caused by the spin of a gyroscope: it resists any attempt to change the direction of the axis of its spin.

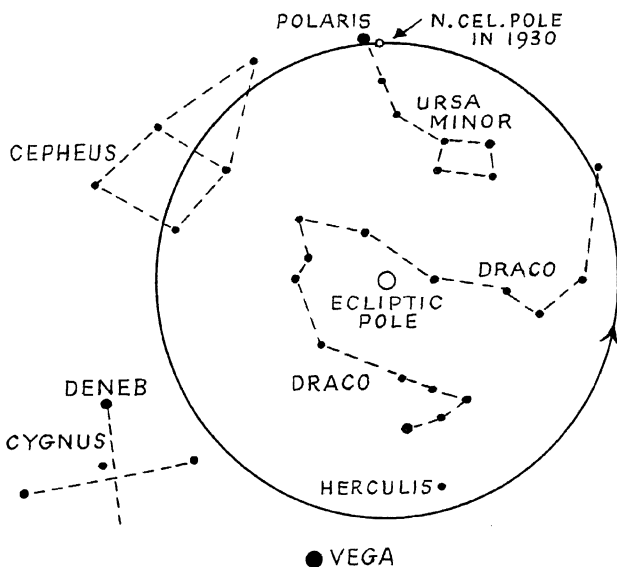
The result of these forces working against each other is a sort of compromise. The Earth does give in slightly to the combined gravitational pull of the Sun and the Moon and swings its axis of rotation in a great circle. This swing is focused at the center of the Earth and does not affect the angle of the Earth's axis in regard to the Sun. The Earth's equator is always tilted  $23\frac{1}{2}$  degrees from the plane of the ecliptic, but the long, slow circling of the polar axis moves the equinoxes westward around the ecliptic, and it moves the extension of the Earth's poles in great circles against the star sphere. This motion of the Earth is completed every 25,800 years. Because of this westward, or backward motion of the equinoxes, this third and much less well-known motion of the Earth is called the precession of the equinoxes.

When man first began to plot the positions of the equinoxes and of objects in space, he found that the vernal equinox lay before the stars of Aries, and he called the vernal

equinox the First Point of Aries. The precession of the equinoxes has now moved the vernal equinox westward into the constellation of Pisces, but this important point is still known as the First Point of Aries.

Polaris, the present North Star, is the third star in historical times to have this distinction. When this point in the skies was first located in about 3000 B.C., a faint star, called Thuban, in the constellation of Draco was the nearest bright star to the celestial pole. Since then, a star in Ursa Minor named Kochab was the North Star for about fifteen hundred years, and now Polaris is. Polaris is less than 1 degree away from the celestial north pole and will be even closer to it in another one hundred years. Then the pole will swing away from Polaris, and in the course of time several other stars will be used successively as markers for the pole. None of them will be as close to the actual point as Polaris is at this

**The path traced among the stars by the extension of the Earth's north pole as a result of precession.**



time, however, although some of them are brighter than Polaris. In about thirteen thousand years, one of the brightest stars will be nearest the celestial pole and will probably be called the North Star, although it is very doubtful that it will be given the name of Polaris, for it is far too well known in its own right. This prospective pole star is Vega, the brightest star in the small constellation of Lyra and the fifth star in order of visual brilliance in all the skies.

Precession is a continuous performance. Each day there is a slight change to the west of the location of the vernal equinox—about one seventh of a second of arc, or one six-millionth of a complete circle—but it adds up. Each year the change is a little more than 50 seconds of arc, and every seventy-one years and eight weeks the change amounts to 1 degree. A degree is twice the angular diameter of the full moon, so it is easy to see that star charts begin to lose their accuracy after a relatively short period. Although the equinoxes take 25,800 years to make a complete circuit of the precessional cycle and get back to their starting places, more accuracy is needed than could be furnished by a chart several years old when an observer is trying to locate a point in space, without dimensions, which he cannot even see without the aid of a great telescope. Each star chart, for this reason, is dated. The date of a chart is called its epoch and is clearly marked on all charts and on star lists and catalogues. There are precession tables, showing by what minute amounts for each period of time the stated position of a star must be changed from that given on a chart or catalogue to obtain its true position.

In addition to these three motions of the Earth, there are several minor motions which do not affect our lives significantly. The gravitational forces between the Sun and the Moon, which cause precession, are not always constant. Changes of position of the Sun and the Moon relative to the Earth cause changes in the strength and direction of these

forces and produce a slight wobbling of the poles of the Earth which overlies the general swing of the precessional cycle. This wobbling is called nutation, or "nodding," and it has a cycle of nineteen years that corresponds to the Moon's over-all cycle of lunation. The Earth's rotation also varies by a very small amount. It is generally slowing down, because of the braking effect of the ocean tides, by about one second every hundred thousand years. Other small changes in the rate of rotation, which have recently been discovered through improved methods of timekeeping, are probably caused by a seasonal shifting of the Earth's polar ice and the atmosphere, although the precise reason for them is not yet known. To complicate matters still further, the location of the poles changes on the Earth without, however, involving the rest of the Earth in the change. This last shift is very slight, but it does cause certain changes in latitude and must be taken into consideration in the accurate determination of terrestrial locations.

The Earth is the most dense of any of the planets. Its over-all mean density compared to that of water is 5.52. As this is considerably more than the density of the Earth's surface material, the central portion of the Earth must be made of metal, probably nickel-iron. We know that the Earth's temperature rises appreciably as we penetrate the crust of the Earth. If this rise is constant—and we have no reason to doubt that it is—the temperature at the center of the Earth must be about 5,000° Fahrenheit, so that any metallic core that the Earth might have must be molten.

The surface of the Earth is composed, generally, of rocky material that has been subjected to two factors that are outside the Earth but in contact with it. These are the hydrosphere, which includes all the waters on the surface of the Earth, and the atmosphere, which is the envelope of gases surrounding the Earth. These two agents change and decay the surface material of the Earth from solid rock into soil.

That part of the rocky surface of the Earth that results from the action of water is called sedimentary rock because it is largely formed from the sediment of mud and sand washed from place to place by moving water. Below this layer, which is very shallow, is a deeper layer of igneous rock, so called because it had its origin in heat. The sedimentary rocks and igneous rocks make up a layer of material called the lithosphere, or sphere of stone, which is about 30 miles deep. The lithosphere is, in turn, supported upon a deep layer of rock called the mantle, below which is the highly compressed and probably molten metal core.

The Earth is a magnet. Its field of force guides man on his journeys by its effect upon the needle of a compass. We do not yet fully understand terrestrial magnetism. The Earth's magnetic field is not stable. Its poles are near the poles of rotation of the Earth but do not exactly correspond with them. There is a small shifting of the magnetic field of the Earth, which moves the magnetic poles about. This would seem to indicate that terrestrial magnetism is not caused by any solid metallic body, but that it may be due to electric currents generated in the core of the Earth.

The Earth is the third planet in order of distance from the Sun. It revolves about the Sun in its elliptical orbit with a mean velocity of  $18\frac{1}{2}$  miles a second. The motion of the Earth in space can be more accurately measured from its position among the stars than by its position relative to the Sun. This more accurate year of the stars is called the sidereal year, from *sidus*, one of the Latin words for "star." The sidereal year is measured by the apparent position of the Sun, as seen from the Earth, in relation to the other stars. It is the period of time taken by the Earth to go completely around the Sun, starting and ending at a particular position relative to the stars. The sidereal year is slightly longer than the calendar year—the tropical year—which is the year of the seasons and which represents the Earth's position in reference only to the Sun. The sidereal year contains 365 days 6 hours



9 minutes 9.5 seconds and is, therefore, 20 minutes 23.5 seconds longer than the tropical year. There are 31,558,149.5 seconds in the sidereal year. With its velocity of  $18\frac{1}{2}$  miles per second, the Earth takes us all on a journey of 583,725,765.75 miles each year—but all that traveling always brings us right back to the place from which we started.

As the Earth travels, we can watch the scenery of space change, just as we watch the terrestrial landscape change as we ride over the surface of the Earth. The nearer objects—the Moon and the planets, for example—appear to be moving much more rapidly than the more distant stars. We see the stars change slowly. The various constellations rise earlier each night as we speed eastward, and they set earlier, too, so that we run a vast gauntlet of stars each year, progressing slowly around an enormous ellipse which gives us a constantly changing view of the sky. We always take the same journey, and the scenery is essentially the same, but the prospect is so vast that none of us can ever hope to see it all. Occasionally new and strange objects emerge from space and remain in our view for brief interludes.

The mass of the Earth—the amount of material it contains—can be measured by an extremely delicate operation which registers the amount of gravitational pull the Earth exerts on a small but accurately measurable mass. From this experiment, the mass of the Earth has been measured to be about sixty-six hundred million million million tons. This is  $1/332,000$  of the mass of the Sun. The ton is a measure of weight, and weight is the effect of the gravitational pull of the Earth upon an object. Only on the Earth do mass and weight have the same measure. It is possible to determine the mass of objects in space only if they are in association with other objects so that the gravitational effect of their influence upon each other can be determined. The only stars whose masses are known are those that are members of a multiple system, such as double or multiple stars. The masses of the planets are known because of their association with the Sun

or with their satellites. In astronomy such masses are usually given as a comparison with the mass of the Earth or the Sun.

The Earth's mass in relation to its size—the amount of space it occupies—gives its density. Since the gravitational effect of any object is calculated from the center of that object, the Earth's mass and the distance from the surface of the Earth to its center give the gravitational pull of the Earth upon objects on its surface. This pull will cause objects to fall toward the center of the Earth with an acceleration of 32 feet per second per second. This means that the velocity of a freely falling object will increase by 32 feet every second during which it is falling. It will fall 32 feet the first second, 64 feet the next second, and so on.

In order to escape from the gravitational pull of the Earth, an object must leave the Earth at a velocity that is determined by the mass and radius of the Earth. This escape velocity is 6.7 miles per second. The square root of the ratio between the mass of a body and its radius will give the escape velocity of that body. Any object that is given a velocity greater than 6.7 miles per second will be able to leave the surface of the Earth and to go into space, where it will fall into the gravitational field of the nearest object more massive than the Earth, which in this case happens to be the Sun. It is not possible to escape completely from the gravitational influence of any body in space, as there is no limit to the distance through which the force of gravity extends. It is possible, however, to go fast enough and far enough so that the gravitational pull of a given body may be so small as to be negligible. Yet we are all captives of the Sun.

#### THE ATMOSPHERE

Most of the molecules of gas that make up the Earth's atmosphere do not, under normal circumstances, travel as rapidly as 6.7 miles per hour. Hence, they remain on or near

the surface of the Earth and provide the priceless combination of gases that are essential to life. Many other gases do travel at speeds in excess of the velocity of escape and have departed from the Earth or must be kept confined if we are to have them available for our use. On other small planets, escape velocities are so low that most gases easily travel rapidly enough to leave their surfaces, and as a result some of these planets have no atmosphere. Mercury and Pluto do not have atmospheres that are detectable from the Earth, and the same situation exists on the Moon. The velocity of escape from the Moon is  $11\frac{1}{2}$  miles per second. There are few, if any, molecules of gas that move at more moderate speeds, particularly if they are subjected to temperatures of more than  $200^{\circ}$  Fahrenheit, as they are from time to time on the Moon. In the case of Mars the escape velocity is almost the same as the normal velocities of most gases when they are slightly warmed. For that reason the atmosphere of Mars has probably been leaking out into space for centuries, and there is little of it left. The giant planets, on the other hand, have high escape velocities and are able to retain many gases that could not remain upon the Earth or upon any of the other small planets. Hydrogen and helium, found on all of the giants, cannot remain free and untrammelled upon the Earth.

To be habitable, the Earth must travel a very narrow road. If the Earth were 10 per cent nearer to the Sun than it is, it would be too hot to sustain life. If it were 10 per cent farther from the Sun, it would be too cold. If the Earth were a trifle less massive, the life-giving gases of its atmosphere would long since have deserted its surface. If it were a trifle more massive, its increased gravitational authority would retain in its atmosphere sufficient gases to upset the present delicate balance between nitrogen and oxygen and would make its atmosphere inimical to life as we know it. Astronomers, knowing of this chancy situation, generally go about on tiptoe and speak in whispers lest some sudden shock throw

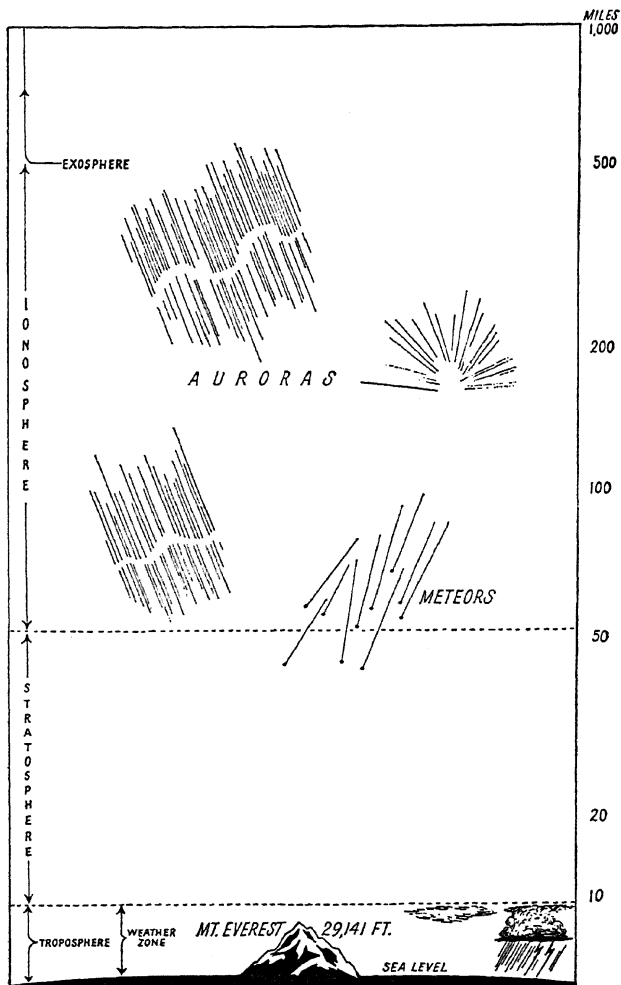
the whole business out of balance.

The present fortunate combination of circumstances in which the Earth finds itself results in the combination of gases that make up the atmosphere of the Earth. We do not know exactly how deep this atmosphere is, but it probably extends outward to somewhere between 600 and 1,000 miles from the surface of the Earth. The most distant point of the surface of the Earth from the Earth's center is the tip of Mount Everest, about 29,000 feet high. This is between 5 and 6 miles, or about 1 per cent of the minimum estimate of the depth of the atmosphere.

The atmosphere is invisible, although we can see impurities carried in suspension in its gases, and we can see accumulations of water vapor as clouds in it. The atmosphere presses down on the Earth's surface with a force of about 15 pounds per square inch. Each of us has enough square inches on the surface of his body to support a weight of about 14 tons. Man has been carrying this weight ever since he began to live upon the Earth, and he would be in a sad way if he were ever suddenly deprived of it. One of the problems of space travel is to substitute some sort of pressure for that of the atmosphere of the Earth.

The density of the atmosphere begins to decrease immediately as we move away from the surface of the Earth. Technically the atmospheric pressure is less at our heads, when we are standing, than at our feet. In reality the first 7 or 8 miles of atmosphere are so much in motion and so churned up that the density and pressure decreases must be considered as average.

The Earth's atmosphere is made up principally of nitrogen and oxygen. Seventy-eight per cent of the atmosphere is nitrogen, and 21 per cent is oxygen. This combination of nitrogen and oxygen is priceless to us for it makes possible our sort of life on the Earth. Other gases in small amounts complete the tally. Argon, for example, is present to the



**Cross-section of the Earth's atmosphere.**

extent of 0.934 per cent, and carbon dioxide to 0.033 per cent. Water vapor—tiny droplets of water—fills in the chinks between the molecules of gas.

The layer of atmosphere immediately about the Earth's surface is the troposphere. This name is another Greek derivative and means "sphere of change." In the tropo-

sphere, which is about 8 miles deep, occurs almost all the motion of the atmosphere—the winds, the storms, all weather generally. This part of the atmosphere is in tumult, somewhere, all the time. In it ride the clouds which always cover an average of 50 per cent of the surface of the Earth, but fortunately not always the same 50 per cent. There can be no definite, decisive boundaries between the various levels of atmosphere, but there is an end, a vague top, to the troposphere, which is called the tropopause. The troposphere contains more than half of the total atmosphere. Three quarters of all the atmosphere lies within 9 miles of the surface of the Earth; 2 miles beyond the surface there is not enough air to support life with certainty and comfort. Thus, oxygen masks are essential for passengers in an unpressurized plane at a height of more than 10,000 feet.

The gases in the troposphere are warmed not directly by the Sun, but by heat that the Earth has received from the Sun and transmitted to the air. If the Sun were directly responsible for the temperature of the troposphere, this layer of atmosphere would get progressively hotter the higher we went. The opposite is what really happens: at the tropopause the temperature has dropped to about 60 degrees below zero Fahrenheit.

Above the tropopause is the stratosphere, a layer of atmosphere that gets its name from the Greek word for "layer." The stratosphere extends upward for another 10 to 12 miles and is relatively stable, although within the last twenty years strong and steady winds with a velocity of 200 to 700 miles an hour have been discovered there. High-flying planes have been helped on their journeys by finding one of these jet streams blowing in the right direction and making use of its force and speed. The temperature in the stratosphere remains constant at about 60 degrees below zero Fahrenheit.

Above the stratosphere is the mesosphere, the middle sphere, whose notable differences from the stratosphere are

a constant decrease in density and a rise in temperature from 60 below to a high of about 175° Fahrenheit. The mesosphere extends outward to about 50 miles from the Earth's surface. At its upper border the temperature drops again, rather abruptly, to about 90 below and then steadily rises through the succeeding regions of the atmosphere to a high of about 2700°. This high temperature is maintained until outer space is reached, where there is no temperature, but where every object has its own individual temperature depending upon its ability either to absorb or to reflect radiation from the Sun. From a purely physical standpoint, because chemical processes are important here, the stratosphere and the mesosphere, taken together, are also known as the chemosphere.

Outside the mesosphere there is a region in which the density of the air begins to be a bit on the low side. Here there is about 1 gram of matter—gas principally—to every 1,000 million cubic centimeters. This compares with 1.2 grams of matter per 1,000 cubic centimeters at the surface of the Earth. It is in this region, at an average distance of about 75 miles from the surface of the Earth, that the aurorae begin to be visible. The aurorae are believed to be caused by the bombardment of the atmosphere by particles of sub-atomic size expelled from the Sun. The intensity of the aurorae increases with an increase of sunspot activity. Outbursts of energy in the form of flares seen on the Sun may be followed in about seventy-two hours by auroral displays, provided the flares are so placed that their outpourings will reach the Earth. The arrival of these speeding particles has sufficient force to deprive the atoms of the atmosphere at this level of some of their electrons. The separation of an electron from the rest of the atom, or even the disturbance of an electron as it revolves about the nucleus of its atom, is accompanied by a tiny flash of energy that we can see from the Earth as the aurorae. Auroral displays are seen as high above the

Earth's surface as 600 miles, which gives us the minimum figure for the depth of the atmosphere. It is possible that the atmosphere extends even farther.

This separation of atom and electron that takes place in this part of the atmosphere is also the source of the name for this region. Such free electrons as would result from this process are called ions, as are the remainders of any atoms that have been thus robbed of their electrons. The part of the atmosphere in which this separation occurs is known as the ionosphere, and the ionosphere is well populated with orphaned electrons and deprived nuclei.

The electron density—that is, the proportion of free electrons per cubic centimeter—is greater than average in several fairly well-defined layers of the ionosphere. These denser layers reflect radio waves that are sent out from transmitting stations on the Earth, bouncing them back to the surface of the Earth instead of permitting them to continue indefinitely out into space; thus, these layers make radio transmission possible. These layers of maximum density have been given specific designations: the lowest is the D layer; the next is the E layer; then come the  $F_1$  and  $F_2$  layers. In the D layer the average electron density is about 10,000 electrons per cubic centimeter. This density rises to about 1,000,000 electrons per cubic centimeter in the  $F_2$  layer. These layers of concentration function fairly well as reflectors of radio waves most of the time, but when the forces from solar flares come tearing into them from outer space, they are battered and disrupted so that they lose much of their ability to reflect electrical impulses efficiently. What amounts to gaps and holes are torn in them, through which the waves sent out from transmitters escape without being reflected back to Earth, and radio communication suffers. This interruption in radio transmission occurs at the same time as the auroral display and is often accompanied in severe cases by a disturbance of other delicate electrical systems. Teletype

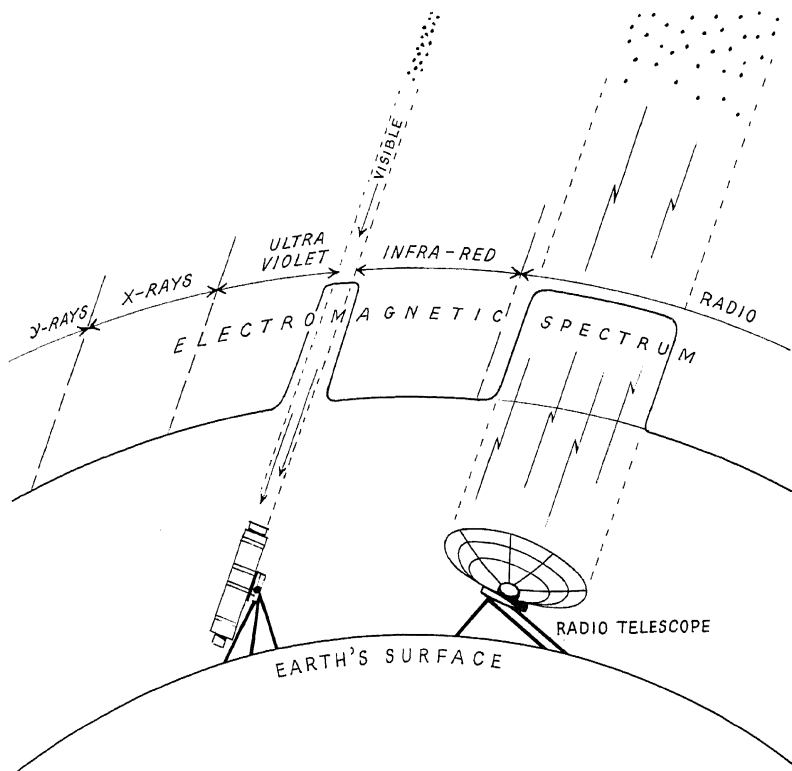


machines begin to transmit gibberish, and short-range police transmitters from Keokuk, Iowa, are heard clearly in Paris, France.

There are winds, if such they can be called, in these tenuous regions—winds that seem to blow in every direction and that reach a velocity of about 1,000 miles an hour. The existence of these winds and their direction and velocity have been determined by their effect in distorting the trails of high meteors and upon the shape and form of aurorae, both of which phenomena occur here.

There is a strange, faint light that can be seen in the atmosphere after night has fallen and that cannot be accounted for by the light of the stars. This light is airglow, and the study of it has given rise to the theory that the molecules of the atmosphere absorb energy from the Sun during the day. When the Earth's rotation carries these molecules away from the Sun and into the shadow of the Earth, this stored energy is released, causing airglow. In this respect the atmosphere produces a weak type of fluorescence.

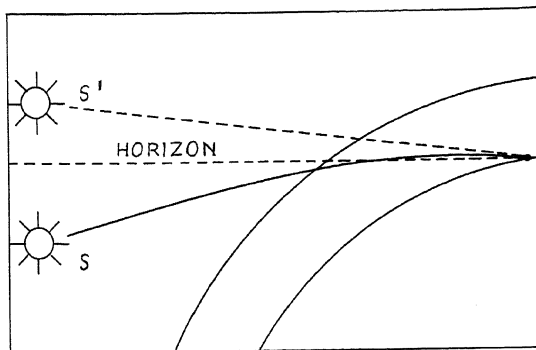
Apart from its inestimable value in providing the inhabitants of the Earth with life-giving oxygen, the atmosphere keeps the Earth's people and its other organisms from sudden death in many forms. It shields them from the constant hail of micrometeoroids, that rain of tiny bodies that pelts the Earth at all times. It also screens out the dangerous radiation from the Sun—radiation whose waves are shorter than those that produce visible violet light and which is called, for that reason, ultraviolet. Some of this ultraviolet radiation does penetrate the atmosphere and gives us sunburn. If more of it reached the Earth, we should not be able to go out-of-doors by day, but we should have to live in some manner that would protect us from this killing storm, and could venture out only at night. There is also dangerous radiation in waves longer than those that look red to us, and it is called infrared. Enough of the radiation is allowed to pass so that the Earth is,



**The two "windows" in the Earth's atmosphere.**

on the average, comfortably warmed. If more were permitted, the surface of the Earth in the daytime would have temperature comparable to the sunlit surface of the Moon—about the temperature of boiling water. High-altitude research, conducted during the International Geophysical Year, had as one of its projects the determination of the strength and the extent of both ultraviolet and infrared radiation.

In addition to the double benefits of nourishment and protection, the atmosphere affects adversely our ability to see and to study the stars, planets, and other objects in space. Light from these objects, including the Sun, is scattered by



**The dense atmosphere near the Earth's surface refracts the light of the Sun at S, making it appear to be at S'.**

dust and water vapor held in suspension in the atmosphere. This scattering of light, together with the power of the atmosphere to bend or refract the rays of light that pass through it, is a serious deterrent to observation. This effect of the atmosphere, which makes objects appear to be much redder than they really are, is familiar to everyone in the reddening of the Sun and the Moon when they are near the horizons and are consequently viewed through many miles of the densest layer of atmosphere. The great accumulation of impurities and water in this part of the atmosphere filters out the shorter waves of light that impart a blue color, but is not able to quench the longer ones that produce red. Hence, we see the Sun and the Moon at such times in the light of their longer waves of radiation, and they appear more red than they really are. The stars are affected in the same way. There is a difference of as much as two magnitudes—two steps in the standard scale of brightness—between stars seen near the horizon when they are rising or setting, and the same stars seen more directly overhead, where there is a minimum of atmospheric interference. This dimming of the stars by the atmosphere is known as extinction.

The atmosphere is responsible, too, for the twinkling of the stars. All of the stars are so distant that their surfaces

are not visible from the Earth by any means of observation. All that we can see of any star, except, of course, the Sun, is a point of light that has no dimension. What reaches us is a thread of light. This thread of light is subjected to every vagary of the atmosphere through which it must pass to reach us. It is bounced hither and yon and twisted and bent in many directions on its way, and our eyes are not equipped to adjust themselves to its changes as rapidly as they occur. Because of them, we see the star fading and growing brighter and apparently dancing in the sky. This is twinkling. The Sun and the Moon do not twinkle because the light we receive from them does not come from one point but from an infinite number of points. Thus, if one ray of light is affected by reflection or refraction, another is there to compensate for it, and we see a steady, clear glow. The same thing is true of the planets much of the time. The surface of a planet, however, is at a tremendous distance and is relatively small. If a planet is seen near the horizon or under adverse atmospheric conditions, it, too, may twinkle.

The general effect of the atmosphere, then, is to make objects look redder than they really are. This effect must be taken into consideration in the accurate estimate of the color of the stars. Refraction, too, changes the apparent position of objects in the sky when they are near the horizon. The Sun, for example, can still be seen for some minutes after it has actually disappeared over the western horizon. The positions of the Sun and of the other stars must be corrected for this peculiarity in such delicate problems as are involved in navigation and in the determination of the precise position of heavenly objects.

During the last few years man has achieved the ability to send out into space artificial satellites which serve as scouts to explore space near the Earth. These tiny packages of instruments have sent back word of the conditions that surround the Earth, conditions that man has been able only to

guess until now. In the main, man's guesses have been remarkably good. He has applied his knowledge of physics with considerable skill and has found that his idea of what he might have to encounter when he ventured into space personally has been sound. He has found that the incidence of micrometeoroids is not dangerous and that the chances of a vehicle in space being struck by a fragment large enough to cause serious damage are about the same as the chances of being struck by a car which he takes many times a day whenever he crosses a city street. This is not too discouraging. He has found that he can protect himself from extremes of temperature by covering the surfaces of his satellites with a striping of reflective paint after the pattern of a barber's pole. By this means he has been able to maintain the interior temperature of satellites at a comfortable 70° Fahrenheit in contrast to exterior temperatures that range from a low of about 250 degrees below zero to a high of more than 500°.

For many months the report of conditions in space furnished by these satellites presented no overwhelming problems. Then satellites began to reach heights of more than 2,000 miles, and new and rather discouraging word came back from them. In 1958 two of the Explorer type of satellite ran into strong and deadly fields of radiation at a height of about 2,000 miles. Details of this radiation showed that it was in a belt lying generally above the equator. The instruments in the satellites registered a powerful impulse that began at this distance and died out at a greater distance. Finally, the evidence indicated a belt of radiation held in position by the Earth's magnetic field.

This theory was tested by the explosion of atom bombs sent up to near the height at which this belt was supposed to lie. The radioactivity resulting from these explosions was carefully studied, and the study confirmed the situation. This belt of radiation was assumed to come from the depths of space and, in part, from the Sun—from those same fierce

flares whose bombardments sometimes penetrate far enough to disturb the ionosphere. The story the satellites had to tell was not a pleasant one. The radiation trapped in this belt was sufficiently strong and deadly to make it precarious and perhaps impossible for a living creature to pass through it and remain alive. As the range of the satellites increased, the existence of a second and more extensive belt was disclosed. This outer belt lies at least 10,000 miles outside the surface of the Earth and is far wider and deeper than the inner belt. In both cases there appear to be openings in these belts over the magnetic poles of the Earth. As the man responsible for the valuable work that disclosed this field of radiation around the Earth was James Van Allen, of Iowa State University, these belts are called the Van Allen Belts.

We seem, then, to be surrounded by two doughnuts of deadly energy, one at a distance of 2,000 miles and a larger one at 10,000 miles. The exploration of this region is still going on, but these barriers would seem to give rather a hard knock to man's ideas of exploring space and getting back to tell his story. There are, it is believed, methods of passing safely through the Van Allen Belts. It is possible to shield the human body against the effects of such radiation behind a wall of lead 8 inches thick or behind 30 inches of concrete. A satellite or space vehicle equipped with either of these two protections, or with any equivalent now known, would be impossibly heavy. An alternative is to pass through the belts at such velocities that any human occupant of a vehicle would not remain in them long enough to be harmed. This will probably be the answer. Rockets are now being planned that will shoot a vehicle through these dangerous regions in a matter of minutes, provided the passengers can stand the terrific beating that the launching of such a high-velocity vehicle would cause.

The Earth has been around for a long time, and man has been trying to determine its age for many years. Some of

his efforts to find out how old his home is have been a bit on the fantastic side, but his acquisition of a knowledge of radioactivity has given him a clock that appears to be accurate. Uranium has the power of spontaneous disintegration at a known rate. In this process of decay, uranium transforms itself into two end products. One of these is helium, which is a gas and does not stay around as a witness to the process. The other end product is lead—lead whose atoms have a peculiar arrangement of protons and neutrons, so that it can be distinguished from ordinary lead. If a bit of uranium has been undisturbed from the beginning of its lifetime up to the present, the original amount of uranium can be determined by traces of its disintegration shown as concentric rings in the surrounding rock, and by the amount of special lead that has been left by the disintegration process. Uranium decays at a rate that causes it to transform half of its substance into lead in four and one half billion years. Traces of uranium found under ideal conditions show that this process has been going on in the Earth for about that length of time. The record of the rocks indicates the age of the Earth at close to four billion years.

Human history covers about five thousand years, or slightly more than one part in a million of the history of the Earth. Man, or traces of the type of creature that developed into man, have been found dating back to about one million years ago, taking up one part in four thousand of the existence of the Earth as an entity. "We are such stuff as dreams are made on; and our little life is rounded with a sleep."

## The Moon

LONG BEFORE THE BEGINNING of time, the challenge of the Moon swung almost nightly across the sky. Changing and changeless, it presented to man, after he had overcome his first fear of it, a whetstone for his imagination. As soon as he had learned to wonder, the Moon entered his dreams. A cylindrical seal from Babylon, carved five thousand years ago, pictures a man mounted on a great bird flying toward a crescent Moon. From this earliest record, the evidence of the searching spirit grows and multiplies. Literature is filled to overflowing with the Moon: its effect upon man and beast; its influence, sweeter than that of the Pleiades, or baleful to the disturbed and unstable soul; and, above all, its allure as a goal for man's escape. The Moon has always been and still is the objective of man's first journey into the terrible mystery of space. The supreme adventure of a trip to the Moon was until a few decades ago something for the imagination alone. Now many who are alive today will see it come to pass.

The Moon is the Earth's only known natural satellite and is the nearest permanent object in space to the Earth. Among the thirty-one known satellites of the solar system, there is only one Moon. The satellites of the other planets have names or numbers of their own and should not properly be called moons. The satellites of Jupiter, one of which is

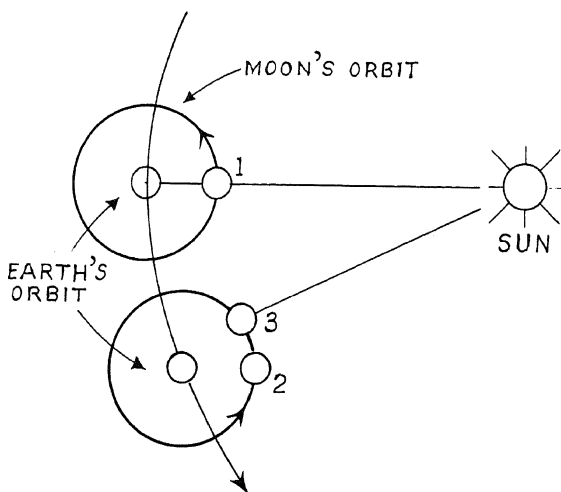


named Callisto, are often spoken of as the moons of Jupiter. This is no more correct than to call the Moon the Callisto of Earth.

The Moon is the largest satellite in the solar system in relation to the size of its primary. This is a statement that often gives trouble. It does not mean that there are no other satellites larger than the Moon in an absolute sense. Three of the four major satellites of Jupiter, for example, are each larger than the Moon, but compared with the size of Jupiter, they are much less significant than the Moon compared with the size of the Earth. The diameter of the Moon is 2,160 miles, which is 27.25 per cent of the diameter of the Earth. The diameter of Jupiter's largest satellite is 3,200 miles, but that is only 3.7 per cent of the diameter of Jupiter. The diameter of Titan, the largest satellite of Saturn, is about 2,600 miles, which is 3.6 per cent of the 71,500-mile diameter of Saturn. The Earth and the Moon might properly be called a two-planet system.

The amount of material in the Moon—its mass—is a little more than one one-hundredth of the mass of the Earth, and the Moon's volume—the amount of space it occupies—is about one fifth of the Earth's. This combination of mass and volume gives the Moon a density that is 0.6 of the density of the Earth and about 3.3 times that of water. This leads us to believe that there is probably no heavy central core to the Moon, as there is to the Earth.

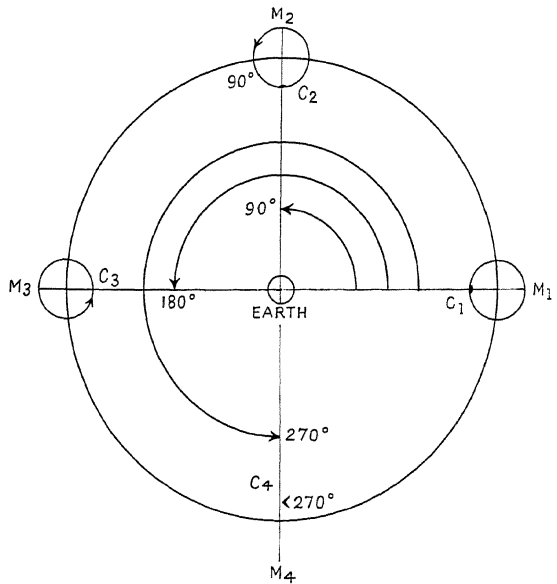
The Moon revolves about the Earth in a period of time that is calculated in two different ways. The length of time that passes between two corresponding phases of the Moon—between one new moon and the next—is 29 days 12 hours 44 minutes 2.78 seconds. This is its synodical period, its period in relation to the Earth and the Sun alone. The interval of time taken by the Moon to complete a revolution about the Earth from a given position against the stars and to return to that same position is 27 days 7 hours 45 minutes



**From position 1, the Moon completes a circuit of the Earth in relation to the stars, when it reaches position 2, but because the Earth has moved in the same direction, the Moon must continue to position 3 to bring itself into the same relation with the Sun as it was at position 1.**

11.47 seconds. This is its sidereal revolution, its revolution in relation to the stars. The discrepancy between the two periods of revolution is caused by the distance that the Earth travels around the Sun while the Moon is moving around the Earth. The Moon revolves around the Earth in a west-to-east direction, and the Earth is revolving around the Sun in the same direction. The Earth moves far enough eastward each month to make the stars appear to move westward against the direction of the motion of the Moon. For this reason the Moon will meet the same stars about two days earlier each month. The Moon, however, has to take two extra days to catch up with the Earth and to place itself in such a position that its phasing will correspond with its last revolution.

The Moon rotates upon its own axis in exactly the same time that it requires to complete one sidereal revolution about

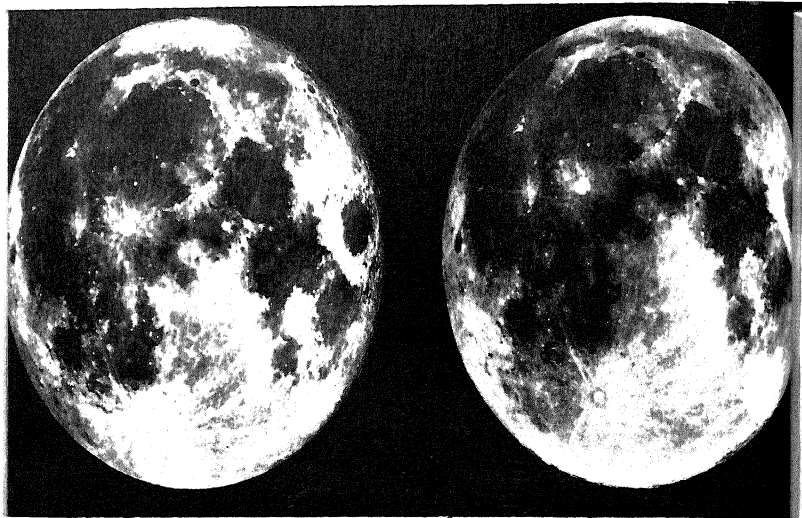


**At  $M_1$ , the Moon presents side C to the Earth.**

**At  $M_2$ , it has moved over one quarter of its orbit and has completed 90 degrees of its rotation, so that  $C_2$  is the same face as  $C_1$ . So with  $C_3$ , since the Moon has completed half its orbit in the same time that it has turned through half its rotation.**

the Earth. Because of this strange coincidence of motion, the Moon always presents the same side to the Earth, which is the only side we ever see from the Earth. The gravitational force of the Earth is so strong over the short distance between the Earth and the Moon that it has gradually slowed down what may once have been a much shorter lunar rotational period. It now holds the Moon locked in place as it revolves.

The revolution of the Moon is irregular, and the orbit of the Moon is highly eccentric. Because of both this and the contrasting regularity of the Moon's rotation on its own axis, we are able to see, over a period of time, farther around one side or the other of the Moon than we could if the two



**The libration of the Moon. Note the difference in the distance between various features and the edge of the Moon's disk in the two pictures.**

motions of the Moon were both even and regular. Thus, we have been able to view a total of more than 50 per cent of the Moon's surface, but never more than 50 per cent at any one observation. This combination of regular rotation and irregular revolution makes the Moon appear to twist back and forth very slowly as it moves about the Earth. We can see farther around one side and not so far around the other side at a given time. At another time we cannot see so far around the first side, but we can see farther around the second side. This apparent nodding back and forth on the part of the Moon is libration in longitude. In addition to this libration in longitude, the Moon travels in an orbit that is not in the same plane as the orbit of the Earth but is tilted at a slight angle to it. This places the Moon occasionally above the celestial equator and occasionally below it. When the Moon is above the equator, we can see farther around the lower pole of the Moon than around the upper pole; and when the Moon is low, south of the equator, we see farther around the upper pole than around the lower. This appar-

ent up-and-down motion is libration in latitude. "Libration" comes from the Latin word for "balancing."

In addition to these two glimpses of additional lunar surface, there is a third that contributes slightly to the excess of over 50 per cent of the Moon's surface that we can see. As the Moon rises and is still low in the east, we can see a trifle farther over its leading side than we can over its following side. As it sets and is low in the west, we get a glimpse in reverse of slightly more of its following edge.

When we add up the bits and pieces of the normally hidden side of the Moon that are given to us through libration, we find that we are able to see a total of about 60 per cent of the Moon's surface. From this evidence we have been led to believe that the hidden side of the moon does not differ too widely in character from the side we have always been able to see. This supposition was startlingly confirmed in 1959.

On October 4, two days after the new moon, Soviet scientists launched a vehicle into an orbit about the Moon. On October 7 this vehicle was about 40,000 miles from the Moon. At that time its velocity was diminished by jets of gas ejected from its leading side, and it was aimed so that cameras it contained could photograph the side of the Moon previously hidden from the Earth. Because of the phase of the Moon at this instant, this hidden side was almost completely lighted by the Sun. The film in the cameras was exposed for 40 minutes. Five days later, on October 12, these photographs, developed automatically aboard the Moon probe, were transmitted to stations in Russia equipped to receive them. The result was man's first picture of the far side of the Moon; his first view of a region whose existence he had known of for ages, but had never been able to see before. The picture that resulted, crude though it was because of the tremendous difficulties of taking and transmission, showed that the far side of the Moon, which was at the time about 70 per cent

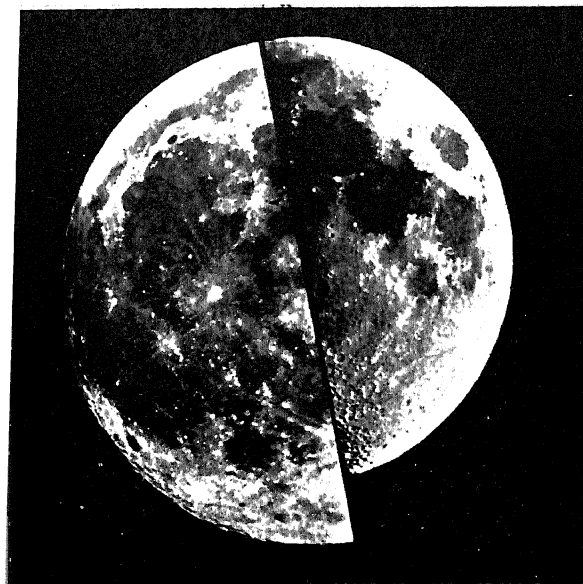


The hidden side of the Moon. Dotted line is boundary of known surface of the Moon. Solid line is the lunar equator.

illuminated, does not differ in general character from the near side. It is, however, apparently more mountainous and contains fewer of the relatively flat areas which are called seas and which look darker than the general rougher surface.

The motion of the Moon through space is extremely erratic. Cecilia Payne-Gaposhkin, a noted astronomer of Harvard University, has estimated that there are more than eight hundred motions of the Moon. Most of these are tiny and of little moment. During each revolution the Moon swings in wide curves around the Earth, coming in some months almost as close to the Earth as it is possible for it to come, or moving almost as far from the Earth as possible, but it does not reach the extremes each trip. The point in the Moon's orbit which is nearest the Earth is called its perigee, and the point of greatest distance is its apogee. These two terms are combinations of Greek words: *peri* is a prefix meaning "near," and *apo* means "far"; *gee* is the root word and means "Earth." We use this same root in "geography," "geology," and so on. The two prefixes are used frequently in astronomy with various roots. Besides "aphelion" and "perihelion," there are "apastron" and "periastron" which are positions farthest from and nearest to a star, respectively. Two fairly recent additions to this family are "periseleno" and "aposeleno," which apply to an artificial lunar probe describing the points in its orbit as being nearest to or farthest from the Moon.

At the nearest possible approach of the Moon to the Earth, the distance between their centers is 221,463 miles. Take from this figure the radii of the two bodies, and a surface-to-surface approach of about 216,000 miles is possible. The greatest possible distance between the Earth and the Moon is 252,710 miles center to center, or about 247,000 miles surface to surface. The distance between the Earth and the Moon is generally given by using the mean between these two extremes—239,000 miles. In an average month the moon



**The change in the apparent diameter of the Moon caused by perspective. The small image is the Moon at apogee; the large image at perigee.**

ranges from a perigee of about 222,000 miles to an apogee of about 250,000 miles.

This variation of distance causes a change in the apparent diameter of the Moon, as perspective works just as effectively in space as it does on the Earth, and objects that are nearer the Earth look larger than those that are farther away. The diameter of the Moon is apparently about 10 per cent larger at perigee than at apogee. It is, of course, impossible to compare these two diameters directly because the moon does not have the faculty of being in two places at the same time, but photographs taken under similar conditions at each of the two aspects show this seeming growth and shrinkage.

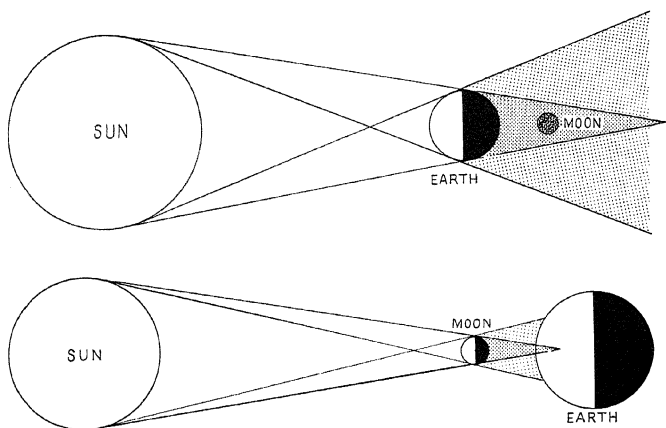
The Moon's orbit is inclined by about 5 degrees to the plane of the Earth's orbit about the Sun. The Moon, then, will cross the plane of the Earth's orbit twice during each revolution. These points of crossing are the nodes of the



Moon's orbit. When the Moon is passing from above to below the plane of the Earth's orbit, the node is the descending node. The node that marks the Moon's transfer from below the ecliptic to above it, is the ascending node. The nodes of the Moon's orbit do not remain in the same locations on the ecliptic, but shift slowly and somewhat irregularly westward as the Moon revolves about the Earth.

The Sun, the Earth, and to some extent all of the other planets have a gravitational effect upon the Moon. The strongest of these effects upon the Moon is probably that of the Earth, which is nearest to the Moon. The Earth and the Sun try to force the Moon to move in an orbit that is in line with each of their equators, but since the planes of the equators of the Earth and the Sun do not coincide, these two forces are not working together. As the Moon combats this pushing and pulling, its nodes are forced into a westward movement, or regression. The regression of the Moon's nodes is not even and regular. The Earth, the Moon and the Sun form a triangle whose angles are constantly changing and whose sides continuously vary in length. Thus, the gravitational effect of the Sun and the Earth upon the Moon is also changing constantly. The total annual effect of these influences upon the Moon's nodes adds up to a westward circling of about 20 degrees. At this rate the nodes move completely around the ecliptic in 18.6 years. The location of the Moon's nodes is important because it determines eclipses of both the Sun and the Moon.

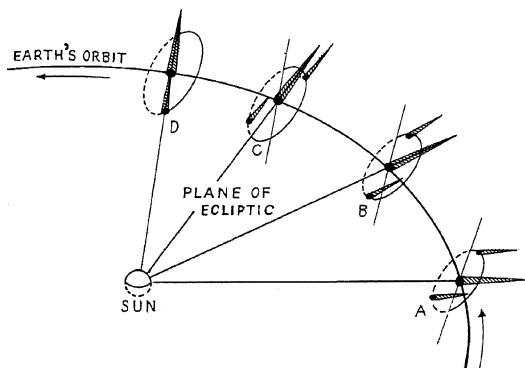
If the path of the Moon about the Earth coincided with the ecliptic, there would be an eclipse of the Sun and an eclipse of the Moon each month. As things are, there can be an eclipse of the Sun only when the Moon is crossing the ecliptic—when it is at one of its nodes—at the same time that the Sun is passing that same point—of course, at a much greater distance than the Moon. Similarly, an eclipse of the Moon is possible only when the Moon is at a node that is



**The passage of the Moon through the Earth's shadow causes a lunar eclipse. A solar eclipse is caused by the passage of the Moon directly between the Earth and the Sun.**

on the opposite side of the Earth from the Sun. The Sun must cooperate here, too. It must be in line, or nearly in line, with the node of the Moon's orbit that is on the other side of the Earth from the node the Moon is occupying and at the same time.

**It is only when the Moon is at or near the plane of the ecliptic that eclipses are possible.**



As many circumstances must combine to produce an eclipse, eclipses are rare. There can be no more than five eclipses of the Sun plus two of the Moon in any one year, and there are many years when we do not get our full quota. We may also have a combination of four eclipses of the Sun and three of the Moon in one year, but this is even more rare. There were three lunar eclipses in 1898 and again in 1917, and there will be another full complement in 1982. Whenever there are five solar eclipses in any one year, we are bound to have seven eclipses of all kinds because there must be a minimum of two lunar eclipses in such years as well. We had seven-eclipse years in 1805 and 1935, and there will be another in 2160. We had seven-eclipse years, with the Moon furnishing three and the Sun four eclipses, in 1787 and 1917, and there will be two other such years in 1982 and 2094.

An eclipse of the Sun occurs when the Moon passes directly between the Sun and a part of the Earth's surface. At such times the shadow of the Moon falls upon the Earth. The Moon's shadow is a cone whose length varies from 236,000 miles to 228,200 miles, depending upon the Moon's distance from the Sun. At its greatest length the shadow of the Moon is obviously shorter than the mean distance between the Moon and the Earth, so that it would appear that the tip of the shadow would more often than not miss the Earth entirely. It should be pointed out, however, that owing to the great eccentricity of its orbit the Moon is often nearer than its mean distance to the Earth. If the Moon is at or near perigee, the surface-to-surface distance between the Earth and the Moon is less than 218,000 miles. It is possible then for the shadow of the Moon to be 18,000 miles longer than the distance from the Moon to the surface of the Earth.

The largest possible diameter for the part of the Moon's shadow that touches the Earth is 167 miles. If this shadow, under the ideal conditions that would give it its greatest

dimensions, strikes the Earth's surface at an angle smaller than 90 degrees, its shape will be an ellipse with the greatest diameter of the ellipse 167 miles. When the Moon is at apogee, the surface-to-surface distance between it and the Earth is 247,000 miles, so that its shadow will fall about 20,000 miles short of the Earth's surface. As circumstances are weighted a bit toward this latter condition, there is often an eclipse that is not complete but during which a narrow ring of the Sun is visible around the edge of the silhouette of the Moon. This is called an annular eclipse, from the Latin word *annulus* for "ring." At such times not only does the greater than average distance between the Earth and the Moon make the tip of the Moon's shadow fail to reach the surface of the Earth, but perspective makes the Moon appear smaller.

The success of an eclipse depends upon the coincidence of the apparent diameters of the Sun and the Moon. Obviously, the Sun is tremendously larger than the Moon, and, equally obviously, it is tremendously more distant. The Sun's diameter is four hundred times that of the Moon, but the Sun is at a mean distance from the Earth of four hundred times the mean distance of the Moon. Or, to put it another way, the Sun and the Moon are each about one hundred and ten times their own diameters from the Earth. Any object that is round or spherical, placed at one hundred and ten times its own diameter from the eye, will have the same apparent diameter as the full moon or the Sun. It is this relationship that Somerset Maugham referred to when he used *The Moon and Sixpence* for the title of a novel. It all depends upon perspective. If the Moon were generally nearer to the Earth than it is, it would so completely cover the Sun at times of eclipse that none of the tremendous prominences on the disk of the Sun could be seen, and only the outer regions of the Sun's corona would be visible. If it were generally farther from the Earth, every eclipse would be annular, and

neither the prominences nor the corona would be visible. We know from experience that during annular eclipses, even though a narrow rim of the Sun is visible around the edge of the Moon, this edge is still sufficient to drown out completely the much fainter light of both the prominences and the corona. Until the invention of the coronagraph, a total eclipse was the only occasion at which either of these two wonderful phenomena could be seen.

If the observer happens to be located in the path of the Moon's shadow, he will see a total eclipse of the Sun. The position of the observer in relation to the center line of the shadow will determine the duration of the eclipse for him. The greatest possible duration of totality during an eclipse is 7 minutes 40 seconds. A number of circumstances must combine, however, to produce an eclipse that lasts so long: the Moon's shadow must touch the Earth at or near the equator; the Moon must be at perigee so that perspective will make it appear larger and so that the part of its shadow that touches the Earth will have a greater diameter; and the observer must be in the center of the shadow and at that part of the Earth over which the shadow passes at local noon. If any of these contributing factors is missing, the eclipse will not be of maximum duration.

The nearer to the Earth's poles that eclipses occur, the shorter they will be. Eclipses that strike the Earth in the extreme north or south last only seconds. Because of all these circumstances, 7-minute eclipses are rare. There was such an eclipse in A.D. 717, and there was another in 1955 when the Moon's shadow touched the Earth in such a way that its path crossed, among other places, the island of Ceylon. In preparation for this eclipse, the island was crowded with astronomers and their instruments. Scientists traveled to Ceylon from all over the world to observe the eclipse. They arrived ahead of time, set up their telescopes, cameras, spectroscopes, and other instruments, and practiced and re-

hearsed and adjusted and readjusted so as to get all that they could out of the 7 minutes during which the Sun was to be hidden by the Moon.

The day came, and the sky was covered with fitful clouds. A few pictures of a hazy Sun showing a rapidly shrinking crescent, 7 minutes of cloudy darkness—and a complete sense of frustration marked the event. Much the same fate befell most of the observing stations along the shadow path of the eclipse of 1958, which crossed the Pacific on October 12 between northern Australia and Chile. There is not too much land along the path, but one tiny island, called Danger Island, was selected as headquarters. Men and equipment were taken as near the island as large ships could go and were ferried in on small boats and helicopters. The natives say that the rain that day broke all records.

On October 2, 1959, an eclipse began at sunrise over the eastern half of central Massachusetts. The shadow path moved eastward across the Atlantic and ended in the Indian Ocean. Elaborate preparations had been made to catch the few seconds of totality visible in the United States and to transmit this spectacle to a waiting world by television. Half an hour before the eclipse, the sky was clear. Ten minutes before the eclipse, the television screens showed the maddened camera crews huddling around their equipment in a driving rainstorm.

In spite of the many and varying motions of both the Moon and the Earth, eclipses can be predicted with great accuracy, as to both time and extent. There is a story of the eclipse of January 24, 1925, during which the shadow of the Moon passed over the northern part of New York City. The southern edge of totality had been calculated to lie in the center of Ninety-sixth Street, which runs roughly east and west across Manhattan Island. To verify this prediction, observers were stationed on both sides of Ninety-sixth Street. Those on the north side, if the prediction were correct, would

be able to see that the Sun was completely covered by the Moon, while those on the south side of the street would see a tiny segment of the Sun still visible, even during the time of totality for those across the street. This is supposed to have been what did happen.

In addition to whatever bits of information they may add to astronomical knowledge, eclipses of the Sun may help to refine and correct measurements of the dimensions of the Earth. The motion of the Moon makes the Moon's shadow move over the Earth during an eclipse with an average velocity of 2,100 miles an hour. The direction in which the shadow travels is always from west to east, in the same direction that the surface of the Earth is moving because of the Earth's rotation. Thus, the Earth's surface seems to be trying to catch up with the eclipse shadow and succeeds to the extent that the average speed of the shadow is reduced, in relation to a point on the surface of the Earth, to about 1,400 miles an hour, or 1,600 feet per second. Since a point on the Earth's equator must move more rapidly than a point nearer the poles, regions nearer the equator will be able to keep better pace with the Moon's shadow than will regions far to the north or south, and an eclipse will last longer when the Moon's shadow falls near the equator. The velocity of the shadow over various parts of the Earth can be calculated so as to furnish valuable information about distances between various points within the shadow path.

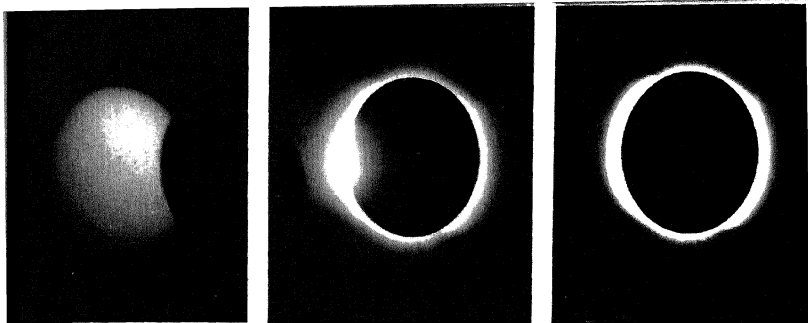
On June 30, 1954, for example, an eclipse began at sunrise in Nebraska. Its path ran northeast from the point of its beginning over a small part of the United States and part of Canada, touched the tip of Greenland, crossed the Atlantic Ocean, the Scandinavian peninsula and central Europe, and wound up at sunset in Jodhpur, in India. The length of the eclipse path was about 8,000 miles and its width was 90 miles. Sunrise in Nebraska occurs about three and a half hours before sunset in Jodhpur, so the shadow traveled

rapidly. Observing stations along the shadow path timed the arrival and departure of the shadow carefully so that the time taken by the shadow between these points gave the distance between them with great accuracy and served as a check upon some of the Earth's less accessible dimensions.

An eclipse of the Sun is a magnificent spectacle. As the Moon begins to encroach upon the Sun, nature is considerably disturbed. The semidarkness that prevails during an eclipse comes over the Earth much more rapidly than does normal darkness at the end of a day and is like the sudden sweep of a great thundercloud. Small birds and animals seek shelter hurriedly when this darkness begins; shadow bands race across the surface of the Earth and may be seen whenever the surface is of a sufficiently light color, as on snow in winter. These shadow bands are the leading edge of the great Moon shadow, broken up and made irregular by its passage through layers of Earth atmosphere at varying temperatures. As the Sun is more and more covered, the air grows appreciably cooler as well as darker, and finally, the brightest stars may be seen. This initial period of an eclipse may take as long as two hours.

The first appearance of a tiny segment of the Moon in front of the Sun is called first contact, and astronomers take pains to time its occurrence with all possible accuracy. An instant before totality, an irregular, curved row of tiny bright points of light flashes on around the leading edge of the Moon. These are Baily's Beads, named for Francis Baily, an English astronomer, who observed the total eclipse of May 15, 1836. In his report of it he described these temporary points of light vividly and accounted, for the first time, for their appearance. Baily's Beads are caused by sunlight shining through the great gorges and valleys of the mountain ranges on the Moon. They come and go in a few seconds. At times when conditions are favorable, some larger depression or irregularity on the Moon's surface may allow such a beam of light to endure





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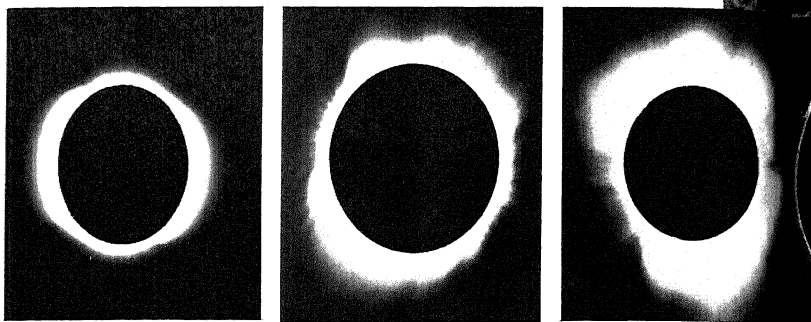
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**The total solar eclipse of June 30, 1954. (1) The edge of the Moon's disk moving before the Sun. (2) A diamond ring an instant before totality as sunlight pours through a valley on the Moon. (3) The first appearance of the corona.**

longer than others and to be of larger dimensions. The effect of this longer-lived and stronger beam is called the Diamond Ring, since it does for an instant look like a great sparkling jewel set in a ring of light. Some of the photographs that have been made of this phenomenon are remarkable.

The complete coverage of the disk of the Sun by the Moon is second contact, and it, too, should be accurately timed. At that instant of second contact, when Baily's Beads have been suddenly extinguished, the Sun's corona is flung into visibility around the black Moon. The corona is the outermost of the layers of gases that surround the central sphere of the Sun. It is so tenuous and delicate that it can be seen only during times of total eclipse or, rarely and incompletely, by means of complicated special instruments attached to telescopes. One such instrument is the coronagraph which in a sense furnishes an artificial eclipse which fairly effectively hides the tremendously bright photosphere, the visible disk of the sun.

The corona extends far out into space around the Sun, at times reaching a distance greater than that between the Earth and the Sun. The corona assumes radically different appearances depending upon the condition of the sun. During periods of low sunspot activity, the corona will extend far-



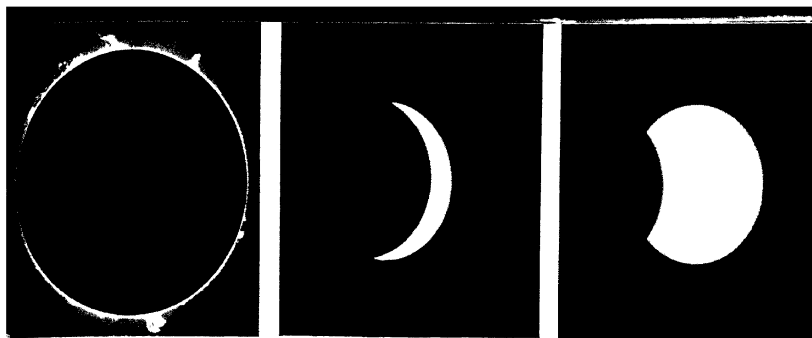
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**(4) The corona a few seconds later than (3). (Center) Total eclipse of May 28, 1900. The corona at a period of low sunspot activity. Note the spicules at the solar poles. (Right) Total eclipse of June 8, 1918. The corona at a time of high sunspot activity.**

ther from the disk of the Sun above the solar equator than it does above the solar poles. Its outline is then more elliptical than circular, and its edge is fairly regular and even. At the poles of the Sun, the narrow, bright filaments of the corona, called spicules, are short, while over the Sun's equator they are much longer. During times of high sunspot activity the corona will flare out generally much farther from the Sun with no great difference between the equatorial and polar regions. Its outline will be irregular but much more nearly circular than during the low sunspot activity periods. Bright streamers that extend far out into space can often be seen in the corona.

The corona seems to pulsate slowly during an eclipse. This pulsation is caused not so much by any actual motion of the gases of the corona or the streamers as by changes in their intensity; it is their varying brightness that gives them the appearance of motion.

Also visible during totality are the solar prominences, bright geysers of rose-colored gases, which are considerably more dense than the material of the corona. During the brief period of totality the prominences seem to remain motionless, although they are really in tremendous turmoil. The prominences, so named because they are prominent,



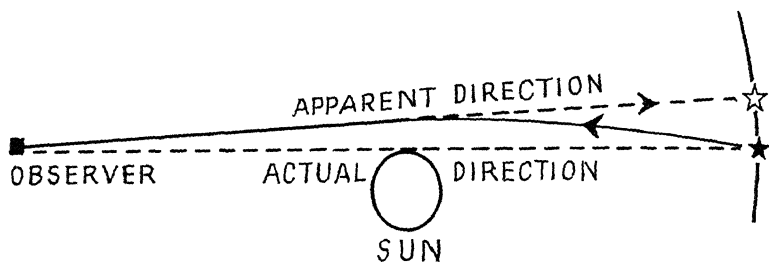
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**(Left)** The whole edge of the Sun showing a variety of solar prominences. **(5)** The crescent Sun revealed as the Moon moves eastward. **(6)** The last stage of the eclipse.

come from the lower layer of the gases surrounding the central Sun, the chromosphere, and are driven out of the Sun by the tremendous forces at work in the Sun's interior. For many years an eclipse provided the only opportunity for seeing the prominences, just as it did with the corona; and at one time, man believed that both the corona and the prominences belonged to the Moon and were made visible only when backlit by the Sun during an eclipse.

The instant the edge of the Sun reappears beyond the Moon is third contact. A second display of Baily's Beads is seen then on the side of the Moon opposite where they appeared just before totality; the corona and the prominences vanish; the stars disappear; the air grows warmer and brighter; birds and animals emerge in confusion from their retreats; and the eclipse is over for everyone except the astronomer who must watch for and time the instant of fourth contact, when the Sun is completely uncovered again.

During total solar eclipses a number of projects have been undertaken that are not concerned with the physical characteristics of the Sun, but that cannot be done at other times. One of the best known of these was the proof of that part of the theory of relativity that held that light is affected by strong gravitational forces. The gravitational force of the Sun was known to be of sufficient strength to affect light, if



**Displacement of light by the Sun's gravitational field makes star appear farther from the Sun.**

the theory were correct. The positions of several stars, located beyond the Sun during a total eclipse, were studied and checked with extreme care. At the time of the eclipse some of these stars could be seen near the position of the Sun and were made visible only because the Moon blotted out the overwhelming light of the photosphere. The positions of the stars seen at this time were again meticulously determined and checked. If light were affected by gravity, the light of these stars should be drawn slightly toward the Sun as it passed it on its way to the Earth. The effect of this diversion would be to make the stars appear farther to one side or the other of the Sun than they really were. This apparent shift was found to exist, and the amount of the displacement agreed very closely with that expressed in the theory of relativity.

During eclipses of the Sun the sky is always searched for objects such as inner planets, asteroids, or comets which may be near the Sun at such times but will be invisible because of its light. One comet has thus been discovered, but no hitherto unknown inferior planets have ever been found.

For about 2,000 miles to either side of the path of the central shadow of the Moon during an eclipse, such an eclipse will be seen as partial. The observer far to one side or the other will see the relationships of the Sun and the Moon at a smaller angle than will an observer in the path of the main

shadow. The nearer an observer is to the center line of the shadow, the greater will be the amount of the Sun's disk covered by the Moon. A partial eclipse will also occur when the positions of the Sun and the Moon are such that the central shadow does not touch the Earth at all, but falls in space. Partial eclipses do not compare in scientific value with total eclipses because any area of the solar disk remaining uncovered will produce sufficient light to drown completely all appearances of either prominences or corona. Partial and annular eclipses may serve to refine measurements of Sun and Moon positions and to give more accurate estimates of distances on the Earth's surface.

Total eclipses of the Moon occur when it passes through the shadow of the Earth. Because this shadow is produced by the light of the Sun, it naturally falls away from the Earth on the side opposite the Sun. At times of lunar eclipses, the Moon must be full since it, too, must be on the side of the Earth opposite the Sun if it is to encounter this shadow. The Earth's cone of shadow is on the average 859,000 miles long. If the Earth is at perihelion, the shadow will be longer than when it is at aphelion. The greatest possible difference in the length of the shadow is about 14,000 miles.

Since the mean distance of the Moon from the Earth is 239,000 miles, the Moon will pass through the shadow at considerably less than the halfway point of the shadow. The diameter of the Earth's shadow at the Moon's mean distance is about 5,700 miles, with a possible variation either way of about 200 miles. The diameter of the Moon is 2,160 miles. The Moon moves slightly more than its own diameter through space in an hour, so that the average duration of a total eclipse of the Moon is about 1 hour 40 minutes. A lunar eclipse is unlike a solar eclipse in that it can be seen by everyone on the night side of the Earth, instead of being confined to a narrow path, provided, of course, that the weather is clear.

The Moon moves from west to east through the Earth's shadow and puts on a leisurely and unexciting show, but one that has a strange weird beauty. The Moon does not disappear at such times, although reasoning would seem to indicate that its passage through a black shadow should cause it to vanish. The false premise here is that the Earth's shadow is complete and black, which it is not. The Moon assumes a dark, red-purple, copper color in the shadow. This strange color puzzled man for years, but we know now that it is the refraction of light through the dense layer of atmosphere that lies directly above the Earth's surface.

These layers of atmosphere absorb the blue light of the Sun and bend the red light around the Earth so that the Earth's shadow is filled with a coppery glow. The only time this color may be seen is when it strikes the surface of the Moon and is reflected back to the Earth during a lunar eclipse.

The central part of the shadow cone of the Earth, the umbra, is surrounded by a more delicate skirt of shadow called the penumbra. The penumbra is so faint and its outline so diffuse that it is difficult to perceive, and only the skilled observer can tell when the Moon enters the penumbra. Its edge is vague, and the irregularities on the Moon's surface increase the difficulties of seeing it. From the known dimensions of the penumbra, however, and from our knowledge of the Moon's velocity, it should take the Moon about half an hour to pass through the penumbra before entering the umbra and about the same time to pass through the penumbra after leaving the umbra on the other side of the eclipse.

An eclipse of the Moon is a beautiful and eerie sight, but it does not have much scientific value. Accurate timing of an eclipse is not possible because the edge of the Earth's shadow on the Moon is vague and irregular as a result of the unevenness of the Earth's atmosphere. An eclipse of the Moon

can, however, be used to determine longitude. Lunar eclipses occur at a given absolute time, usually calculated to the prime meridian at Greenwich, England. Any variation from this time, which is known and published, will give an observer his distance either east or west of the prime meridian, and this distance is longitude. Studies can also be made of the drop in the surface temperature of the Moon during a lunar eclipse. This temperature change is caused by the Moon's plunge into the shadow of the Earth and the consequent cutting off from it of the direct light of the Sun. Sometimes the occultation of faint stars by the Moon can be observed at times of total lunar eclipses when the normal light of the full moon would otherwise completely overwhelm the faint light of these stars.

The size relationship of the Earth and the Moon is only partly expressed by the difference in their respective diameters. The diameter of the Moon is 0.273 of the diameter of the Earth, but the surface of the Moon is about  $\frac{1}{4}$  of the surface of the Earth, and the Moon's volume is about  $\frac{1}{49}$  of the Earth's. The mass relationship is more important, since it is largely responsible for the difference between the surface gravities of the Earth and the Moon. The mass of the Moon is  $\frac{1}{81.5}$  of the mass of the Earth. Because of both this and the difference between the diameters of the two bodies, the surface gravity of the Moon is  $\frac{1}{6}$  of the surface gravity of the Earth. If you weigh 180 pounds on the Earth, you would weigh only 30 pounds on the Moon.

Such a small surface gravity is not sufficient to retain any appreciable atmosphere upon the surface of the Moon. There may be some tiny traces of gas inside the deep depressions on the surface, and it is possible that some radioactive gases may escape from fissures in the Moon. For all practical purposes, however, it may be said that the Moon has no atmosphere. There is certainly no moisture there. This means that there is no weather, no sound, and very little color. The Moon is

a dead and silent world.

Because of this lack of atmosphere, the Sun seen from the Moon would appear as a disk almost white and blinding in its intensity. The rose-colored prominences around its edge would always be visible, as would the long, pearly streamers of the corona, but it would be more difficult and painful to look at the Sun from the Moon than from the Earth. Stars would be visible during the lunar day as hard, unwinking points of light in a black sky, although the glare of the lunar landscape would be so blinding that only the brightest stars at a wide angle from the Sun could be seen. During the lunar night of fourteen Earth days, however, so many stars would be visible that it would be difficult at first to trace the outlines of even the most familiar constellations.

If the observer were on the side of the Moon that constantly faces the Earth, he would see the Earth going through phases much like those of the Moon as seen from the Earth. The Earth, however, would not appear to move across the sky but would remain essentially in the same position, while the Sun and the other stars would appear to stream past it, from left to right. This is because the same side of the Moon is always facing the Earth, and minor lunar motions would make the Earth appear to move only slightly up or down or from side to side. At the time of new moon, when the earthward side of the Moon is dark, the Earth itself would be full and would give about forty times as much light to the Moon as the full moon gives to the Earth.

As the Moon moves around the Earth, it is at the time of new moon, about 239,000 miles nearer the Sun than is the Earth. At the time of full moon, it is farther from the Sun than the Earth is by about that same distance. All in all, the Moon is in the same part of space as is the Earth and receives about the same amount of energy from the Sun, volume for volume. Most of the differences between the surfaces of the Moon and the Earth are caused by the lack of atmosphere



and water upon the Moon. During the lunar day, at a point directly beneath the Sun, the temperature of the Moon's surface is about  $214^{\circ}$  Fahrenheit, or about the boiling point of water. At the beginning or end of the lunar day, when the Sun is just above the lunar horizon, the temperature is about 58 degrees below zero, and during the long lunar night the temperature falls as low as 243 degrees below zero. This extreme range is run through very rapidly as day and night succeed each other on the Moon; the descent or ascent from either of the two extremes to the other is accomplished in a few hours.

It would be difficult for persons accustomed to the partial darkness of the Earth by night and to the vague shadows cast by objects upon the Earth to realize the complete blackness of lunar night and shadows. At night, of course, there would be stars, far brighter and more vivid than we can see them from the Earth. If we were on the earthward side of the Moon, there would be considerable light from the Earth, which reflects back more than half of the sunlight that strikes it. Lunar shadows, however, would be intensely black because there is no air there to spread and scatter the sunlight. The temperature in any considerable shadow on the Moon would be bitter cold, too, even though it were full, blinding, and boiling-hot daylight outside the shadow.

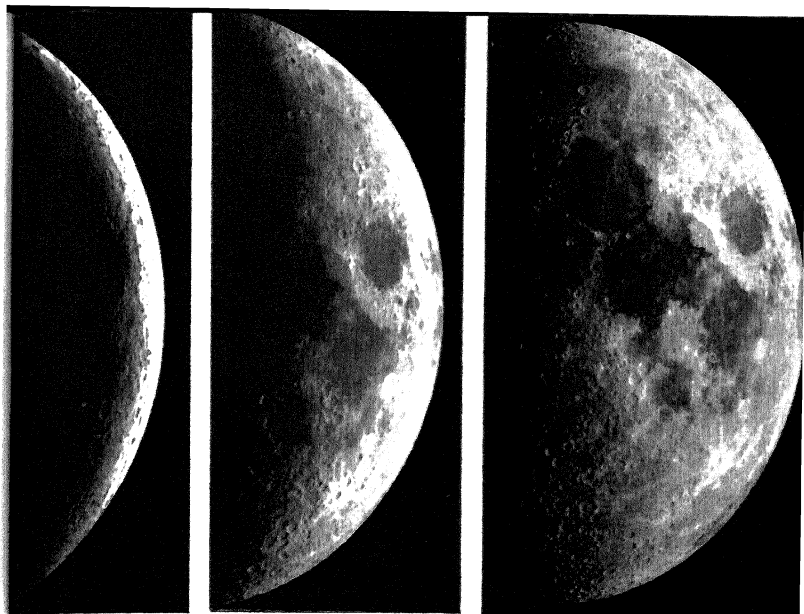
The surface of the Moon must be subjected to a continuous bombardment of meteorites. Meteors rarely reach the surface of the Earth, since they are vaporized by friction as they pass through the Earth's atmosphere. In spite of the small number that survive this ordeal by fire, the incidence of meteors reaching the atmosphere of the Earth is calculated to be on the order of one hundred million every twenty-four hours. On the Moon, without a protecting atmosphere, these particles must pelt the surface constantly at velocities of up to 10 miles a second. There would not be as many particles striking the Moon in a given period of time as strike the

Earth's atmosphere, because the Moon is a smaller target and its surface gravity is weaker, but preliminary estimates put the probable daily count conservatively at one million.

The vast majority of meteorites are tiny particles, not so large as a grain of sand. This bombardment, which has been going on for billions of years, must have deposited a substantial accumulation of meteoric dust upon the Moon. Various estimates of the depth of this dust carpet range from about 3 feet to several miles. Without any air between the dust particles, this blanket would be solidly packed and much shallower than an accumulation of the same number of particles on the Earth. Gerard Kuiper, an American astronomer now at the University of Arizona, who has made long and detailed studies of the solar system, postulates that the exposure of these particles to the unremitting and unshielded radiation from the Sun during a long succession of lunar days has caused radioactive decay in them and that this dust is not soft and deep but has degenerated into a hard, crumbly shell much like slag.

The general color of the Moon is about that of slate or sandstone, and the Moon ranks with the planet Mercury as being the poorest reflector of light in the solar system. The Moon's albedo—its power to reflect light—is only 7 per cent; it absorbs 93 per cent of the light that falls upon its surface. It is only because the Moon is so near us that it looks as bright as it does.

At times of astronomical new moon, we do not see the Moon at all, for then it is generally in the region between the Earth and the Sun, so that its side that is turned toward the Earth is also turned away from the Sun. Since it does not, therefore, receive any light from the Sun, it cannot reflect light to the Earth. As the Moon moves around the Earth, traveling always to the east, the angle formed by the positions of the Sun, the Earth, and the Moon of which the Earth is the vertex is constantly changing. As the angle grows

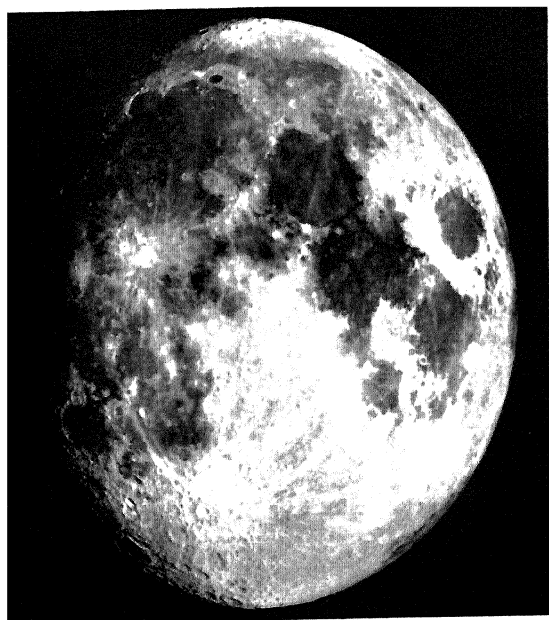


**(Left)** The crescent Moon, 3 days after new. **(Center)** The Moon 5 days old. The dark area above center is the Mare Crisium and below it is the Mare Foecunditatis.

In all these photographs, north is at the top and west is to the right. **(Right)** The Moon, age 8 days. The chain of three Maria east of the Mare Crisium has come into view. The Mare Foecunditatis is the lowest, then the Mare Tranquillitatis and the Mare Serenitatis. The small dark area to the east is the Mare Nectaris. The three prominent craters above the Mare Serenitatis are Eudoxis and Aristoteles with Burg to the west.

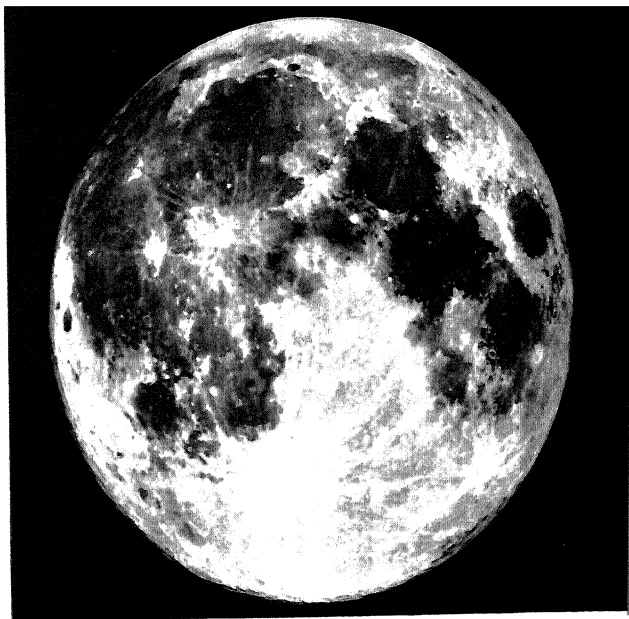
larger, we can begin to see the extreme edge of the lighted side of the Moon. This slender crescent is what is popularly called the new moon, although technically it is the Moon at a phase age of a day or two—the crescent after new.

The constant revolution of the Moon and the resulting increased angle between the Sun and the Moon as seen from the Earth, bring more and more of the lighted side of the Moon into view, and as the Moon is slowly rotating, it is sliding more and more of its earthward side into sunlight.



**The Moon, age 11 days. The gibbous Moon shows much of the Mare Imbrium with the Sinus Iridum in the upper left of the picture. Right of this is the dark crater, Plato. South of the Mare Imbrium is Copernicus with its irregular ray system. Above Copernicus is the Caucasus Mountain range. Curving from the north toward Copernicus are the Apennines. South of Copernicus is the Mare Nubium and dominating the entire southern section is the bright crater Tycho whose ray system extends over the southern third of the picture.**

After about a week we are able to see half the lighted half of the Moon. As half of one half is a quarter, this phase of the Moon is called the first quarter moon. During the next few days the Moon moves farther and farther into sunlight, and the terminator—the line between the lighted portion and the dark portion—looks bowed out. This is the gibbous Moon. “Gibbous” is a lovely word, coming from the Italian *giboso*, which means “hunchbacked.” In about two weeks from new moon, the Moon has completed half of its progress around the Earth and has reached the side of the Earth oppo-



**The Moon, age 14 days. The full moon. Compare the flat tone of this picture with the three-dimensional effect of the previous photographs. This is the Moon's noon, and the Sun, directly overhead at this phase, casts no shadows.**

site the Sun. Here it rises as the Sun sets and sets as the Sun rises, and the side that is turned toward the Earth is fully lighted. This is full moon.

After full moon the process is reversed. For a week the Moon goes through a nightly series of constantly diminishing gibbous phases until we see only the half of the lighted side that we did not see at first quarter. This is called, most logically, last quarter. Then comes continuing diminution and, finally, early in the morning before sunrise, the crescent before new is visible. The use of "crescent" here is a contradiction in the strict sense of the word. "Crescent" means "growing," but usage has appropriated the shape of the growing thing instead of the true meaning of the word, so that both the new moon, which is really crescent, and the old moon, which is not crescent but has a crescent shape, bear



**The Moon, age 17 days. The eastern side of the Moon reveals the Oceanus Procellarum, the great plain that covers much of the northeastern region. East of Copernicus is Kepler, and northeast of Kepler is Aristarchus, the brightest crater. The dark spot below east center is Grimaldi.**

the same name. To distinguish between them, the new moon is called the waxing crescent or the crescent after new, and the old moon is the waning crescent or the crescent before new.

Because the Moon is, generally speaking, in the opposite part of the ecliptic from the Sun, it is high in the sky at those seasons when the Sun is low, and low when the Sun is high. The winter Moons are well above the southern horizon on clear nights, and the summer Moons appear lower. The eastward motion of the Moon is in the same direction as the rotation of the Earth, so that the Moon is constantly gaining on the spin of the Earth and hence rises about 50 minutes later each night on the average than it did the night before, because the Earth must spin on a bit in order to catch up with



**(Left)** The Moon at 20 days shows much of the eastern detail. Aristarchus stands out sharply in the dark Oceanus Procellarum. Below Tycho, to the south, is Clavius, the largest crater. **(Center)** The Moon at 23 days shows that Kepler is a small symmetrical crater whose ray system gives it prominence at earlier phases. Above it, Aristarchus asserts its reputation as the brightest feature of the Moon. **(Right)** The crescent before new—the Moon at 26 days.

it. This average lateness of the Moon is its retardation. Actually the Moon may rise as much as 80 minutes later than it did on the previous night, or as little as 13 minutes later. When the Moon is in that part of the sky in which the vernal equinox is located, its normal retardation in rising is small in the northern hemisphere, but it sets much longer after the previous day's setting. The Moon is in this position in the autumn season in the northern hemisphere, and at such times the full moons of September and October rise only a few minutes later than the nearly full moon rose on the previous night. The full moon of September is called the Harvest

Moon because of this peculiarity, on the theory that the prolongation of light furnished for several nights by the full or nearly full moon enabled the thrifty and hard-working farmer to carry on with his harvesting for a few hours longer than his normal day. As the complaisant October full moon has made it possible for the greedy hunter to go on tracking animals after the Sun has set, it has been given the name of Hunter's Moon.

According to the astronomical system of measuring brightness, the Moon at the full has a magnitude of  $-12.55$ . This makes it the second brightest object, visually, in space, but it is a poor second, for the Sun is 400,000 times as bright. If the entire sky were filled with full moons placed edge to edge, they would still give only one fifth the light given by the Sun. It is difficult to speak with certainty of the light of any phase of the Moon except the full phase. At other phases the angle at which sunlight strikes the surface of the Moon produces countless shadows, large and small, each of which subtracts its quota from the total of the Moon's light. The quarter phases, during which we can see approximately half of the earthward side of the Moon illuminated, give only about one ninth of the light of the full moon. The two quarters are not equal in the amount of light they reflect. The last quarter moon has a much greater part of its area in the great smooth plain of the Moon's only ocean—the Oceanus Procellarum, the Ocean of Storms—and since the smoother parts of the Moon's surface are not as efficient reflectors as the mountainous regions, the last quarter moon gives somewhat less light than the first quarter.

The most obvious of the many influences that the Moon has upon the Earth causes the phenomenon of the tides. A great ocean swell sweeps about the Earth constantly, flowing past islands and continents, at the behest of the Moon. It is the gravitational pull of the Moon, with some assistance from the Sun, that causes tides.



As the Moon moves about the Earth, its gravitational force is felt most strongly at that part of the Earth nearest it, the surface of the Earth directly beneath the Moon. Here this force lifts the fluids of the Earth slightly into a bulge, which is carried about the Earth under the Moon. Underneath the Earth's oceans is the Earth itself, slightly farther from the Moon than the waters upon it. The Moon pulls at it, too, but less strongly because of its greater distance from the Moon. The solid body of the Earth is slightly affected and distorted by the insistent tugging of the Moon and has a minute tide of about  $4\frac{1}{2}$  inches. The solid Earth is also pulled away from the waters on the side of the Earth away from the Moon, again because of the distance difference, so that a second tidal bulge is left opposite the one directly under the Moon.

These tidal bulges would move steadily about the Earth, keeping pace with the Moon, if it were not for the continents that act as barriers to interfere with the sweep of the tide. As it is, the variation in the timing of the tides generally follows the retardation of the Moon. Successive tides are on the average 50 minutes later each day than on the previous day.

The Sun has its part, too, in the phenomenon of the tides. It is enormously larger than the Moon and more massive, but it is also about four hundred times farther from the Earth than the Moon is. Its gravitational effect is thus much smaller. The Sun does make itself felt, however, particularly during periods of new or full moon, when the forces of the two bodies are acting most nearly in the same line, in either the same or the opposite direction. At such times the tides in the Earth's oceans are more extensive, higher and lower, than at other times. These extreme tides are called spring tides, not because they occur in the spring, but because they spring upward more vigorously on the shore.

At times of the quarter phases of the Moon, when the Moon and the Sun are more nearly at angles of 90 degrees from each other, their forces are no longer working together

but are pulling at right angles to each other. This has a subduing effect upon the tides, which are then called neap tides. "Neap" comes from an Anglo-Saxon word that means "scanty."

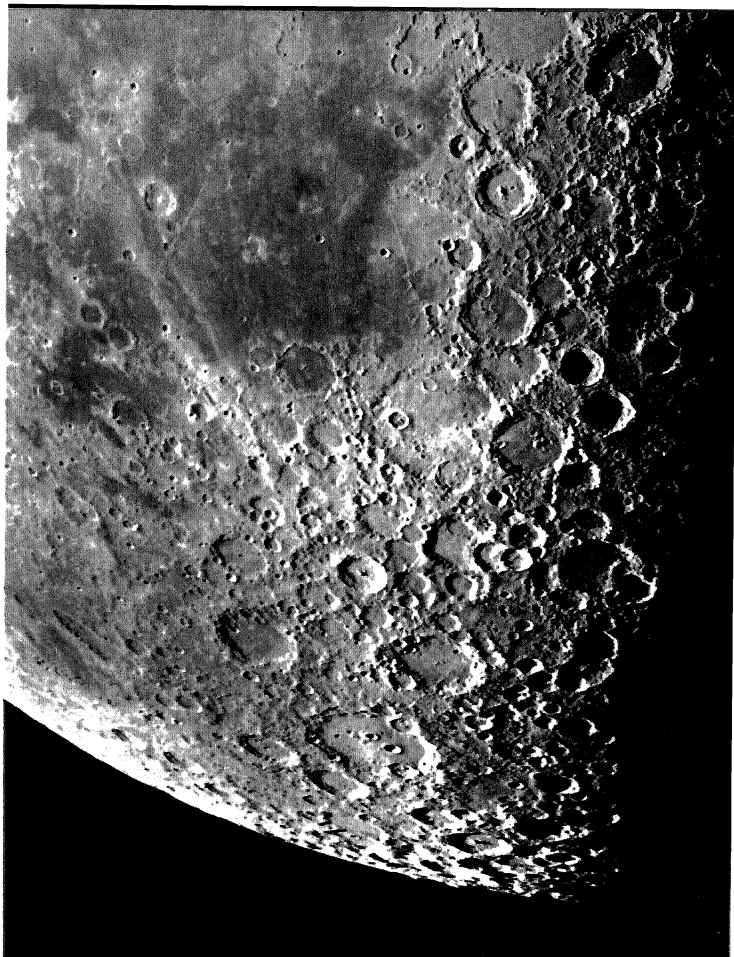
This constant tidal process has a small but measurable effect on the rotation of the Earth. The friction between the motion of the tides and the solid surface of the Earth and the pull of the Moon and the Sun which is at times counter to the direction of rotation of the Earth, have a braking effect on rotation. This effect slows down the spin of the Earth at the rate of 1 second every one hundred thousand years.

In a similar fashion the Earth has a gravitational pull upon the Moon. Its forces are about eighty times as strong on the Moon as are the forces of the Moon upon the Earth. The tidal pull of the Earth on the Moon certainly distorts it, although there is no water to show this effect quickly. The diameter of the Moon is larger in line with the Earth than it is at right angles to the Earth's position.

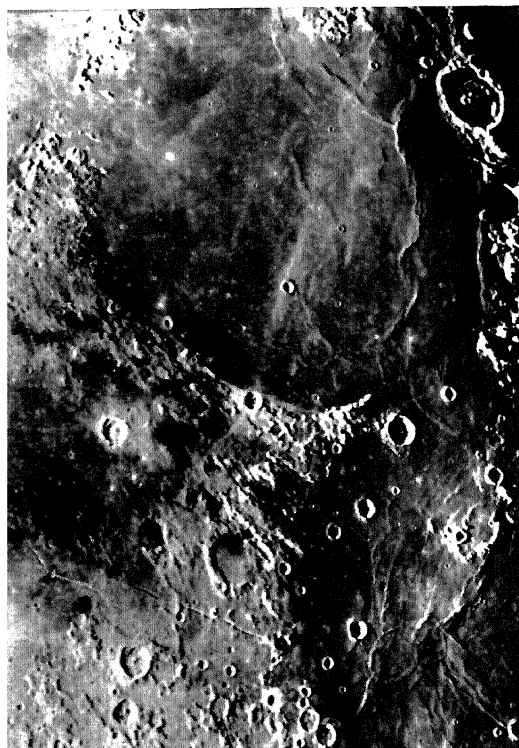
#### THE SURFACE OF THE MOON

The Moon is near enough to the Earth so that surface markings of only a few hundred feet in diameter can be seen upon it through large telescopes under favorable conditions. These favorable conditions are always at phases other than full moon, for at full moon the lack of shadows deprives the surface irregularities of the Moon of a three-dimensional effect. Some of the most impressive features of the Moon practically disappear at full moon.

The most remarkable features of the lunar landscape are the so-called craters, those generally circular markings, of which some thirty thousand have been mapped. The craters range from mere dots of about a mile across to great walled plains 150 miles or more in diameter. The majority of the craters have been named for individuals whose services to



The crescent before new—the Moon at 26 days. The southern portion of the Moon. Below the center of the picture is Tycho. Below and to the left of Tycho is Maginus; to the right is Longomontanus. Below and between these last is Clavius, diameter about 150 miles. The Mare Nubium stretches away to the upper part of the picture. Along its western border, the three craters near the top of the picture are Arzachel, bottom, Alphonsus, center, and Ptolemaeus, top. It was in Alphonsus that the Russian astronomer, Kozyrev, saw what appeared to be volcanic activity. Above the center of the picture is the narrow, bright streak of the Straight Wall.



**Mare Serenitatis and part of Mare Tranquilitatis. The Haemus Mountains curve to make the southern shore of the Mare Serenitatis. Near their western end is the crater Plinius. The prominent isolated crater in the Mare Serenitatis is Bessel. The indefinite white spot northeast of Bessel is Linné, one of the most puzzling lunar features.**

astronomy or to science have been notable. There are a few interlopers who have been given craters in the past, but under present rules an individual must possess two definite qualifications in order to have a crater named for him. He must have been a great astronomer, and he must be dead.

Certain portions of the Moon's surface, notably the regions around its south pole, are so thickly studded with craters that there is no end to them, while the dark, smooth areas called maria, or seas, are practically free of them. In addition to the

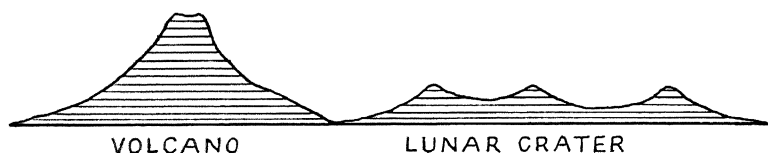
craters and the seas, there are several imposing mountain ranges whose peaks often rise to 25,000 feet and more above the Moon's surface. The mountains of the Moon are much higher than the mountains of the Earth, considering the relative sizes of the two bodies. A peak on the Moon of 25,000 feet would be matched by a terrestrial mountain 100,000 feet high. On the Moon, there are mountain ranges and isolated peaks, cliffs and valleys, and, indeed, almost every other type of surface formation that the Earth possesses except those caused entirely by water or atmosphere.

Telescopic observation has not disclosed any changes in the lunar landscape since man first began to observe and note the condition of its surface, although several false alarms have been sounded. In each case investigation has revealed that the supposed changes were really shifting shadows whose motion over the Moon, as it progressed through its cycle of phases, temporarily changed the appearance of various objects. The pocked and scarred surface of the Moon does clearly indicate that changes of a cataclysmic nature have obviously occurred in the past. Something must have happened to produce all those craters. There has been no lack of theories to explain what that something may have been. It is amazing how many different ideas have been put forth to account for the formation of the solar system and for the craters on the Moon.

The earliest explanation offered was that the craters are extinct volcanoes. The lunar craters, particularly the large ones, have only a superficial resemblance to volcanic craters. Not only are they much larger than terrestrial craters, but there are important structural differences. Volcanoes are pointed, cone-shaped formations with a small opening at the top, whereas the lunar craters are relatively shallow basins with gently sloping side walls. Many lunar craters are so wide that, to an observer in the center, the surrounding wall would be out of sight below the horizon. It may be that the great

difference in surface gravity between the Earth and the Moon accounts for the great difference in formation between their craters. Sluggish eruptions on the Moon ages ago, encountering less gravitational resistance, might perhaps have made possible the formation of craters with tremendous diameters.

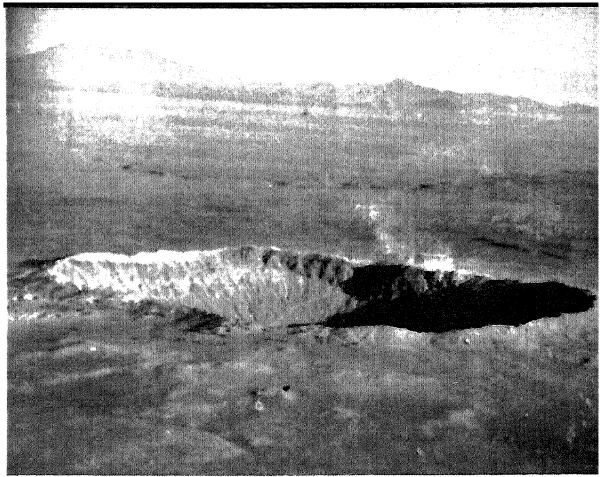
A second hypothesis has the craters formed by enormous bubbles of gas rising from the Moon's interior, pushing up the surface of the Moon and finally bursting, leaving a ring-shaped scar. Still another idea holds that the Moon was once covered by a thick sheet of ice. Heat from the then molten interior of the Moon melted the ice in places, leaving cup-



**Comparison of cross sections of terrestrial volcanic craters and lunar craters.**

shaped depressions. Water from the melting ice evaporated, but before the water vapor could escape, it was deposited around the edge of the exposed region, forming a high rim. In view of the fact that the temperature on the Moon's surface directly under the Sun is 214° Fahrenheit, the ice-layer theory seems a bit strained. Even more fantastic is the suggestion that the craters are the work of micro-organisms such as those that built terrestrial coral atolls.

The explanation for the craters that is held by many astronomers is that they are the result of impacts from the constant meteor bombardment. There appears to be considerable evidence to support this theory. The idea that the craters were formed in this manner was first advanced by a German astronomer, Franz Gruithuisen, in 1822, but it did



**Meteor Crater, near Winslow, Arizona.**

not win many adherents. The impact hypothesis was again advanced by Richard Proctor in 1873, and he is usually given credit for being its originator. In 1909 T.J.J. See, a prolific writer on astronomical matters, went even farther and declared that the battered surface of the Moon was the result of the impact not only of meteoroids but of asteroids as well. The difference is, after all, mainly one of size. See claimed that the great, smooth surfaces of the maria, the so-called lunar seas, could have been formed when a larger body, such as an asteroid, crashed through the surface of the Moon ages ago at a time when there was perhaps some molten material under that surface. This molten material was released and spread over large areas of the Moon to form the maria.

In 1948 Ralph B. Baldwin, author of *The Face of the Moon*, presented new evidence in favor of the meteoric impact hypothesis, although not in the form in which it was originally conceived. Proctor had thought of the craters as being formed while the Moon was still only partly cooled. The meteors would then strike its surface while that surface was still in a plastic condition, leaving holes similar to those that can be produced by hurling pebbles into stiff mud. Baldwin has shown, on the other hand, that the assumption of a plastic

surface is not necessary. A meteorite would collide with the Moon's surface with such violence that the portion of it that made contact with the surface would be vaporized with the effect essentially like that of the explosion of a bomb. The potential energy of the meteorite, based upon its mass and the velocity at which it was traveling, would be instantly transformed into heat when its motion was stopped. The resultant explosion would blow a hole in the Moon much larger than the original diameter of the meteorite. In the original theory the craters were supposed to have been formed simply by the mechanical force of the meteorite's gouging a hole in the ground.

Such an argument would not be essentially convincing without additional evidence. Such evidence has been obtained from measurement of terrestrial shell craters, of which we have unfortunately a large supply. These show a definite relationship between depth and diameter. Baldwin has shown that the same relationship holds for craters on the Moon. In fact, if a curve depicting graphically the relationships of diameter to depth of the smaller terrestrial craters is extended, it fits directly into the curve for the same ratio for lunar craters, forming a continuous, unbroken sequence. Baldwin is convinced that the lunar craters are essentially the same as man-made craters, except that some of them are on a vastly larger scale.

Baldwin has extended his theory so that it applies not only to the craters but to the maria as well. A few paragraphs ago, See's theory was mentioned, which required a puncture of the Moon's crust by asteroids to create the maria. Baldwin points out that the asteroids, sometimes miles in diameter, could be reduced to pools of molten rock by the heat generated by impact. This lava flowed over the surface in a flat sheet, covering and filling the irregularities it encountered. The smooth surface was later bombarded by meteorites that formed new craters, which were, in turn, filled again by lava from new asteroids, and the process continued until space



in the vicinity of the Earth and the Moon was generally swept clean of large meteoroids and asteroids, the bombardment ceased, and the Moon was left with its present appearance. There are many half-hidden craters on the Moon, parts of whose walls rise above the level of the great flat maria, and these do look as though they had been drowned by a sea of lava.

There are a number of factors that cast some doubt upon the impact theory. One such factor is that most of the craters are practically circular. If they were caused by meteorites, the meteorites must have struck the Moon at right angles to its surface. It does not seem completely reasonable that so large a percentage of them could have come in so directly. Some must have struck at smaller angles to the Moon's surface and made elliptical or elongated depressions. The size of some of the craters seems too large to have been caused by impact. With one or two exceptions the craters are a bit shallow for their diameters, as though all of the force of the hypothetical explosion had been upward from the surface. This objection may be met by the theory that much of the original depth of most of the craters has been filled up with dust.

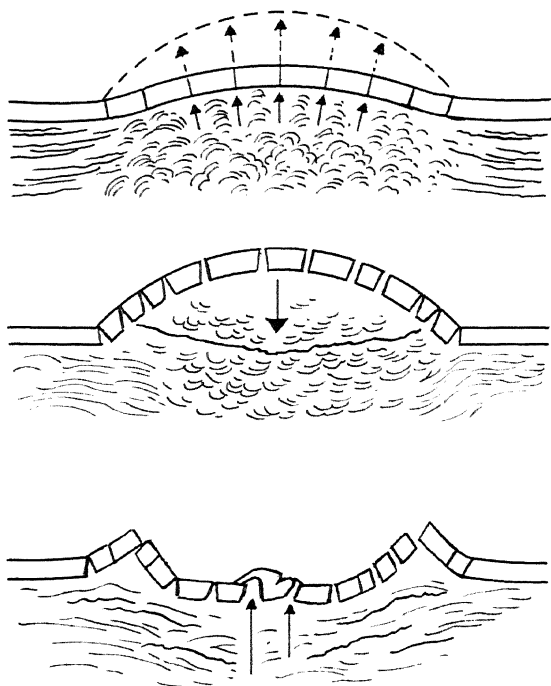
The latest theory holds that the Earth and the Moon were formed at the same time and that the Moon was much smaller than it is now. It was also, at that time, the largest of a vast company of satellites that revolved rapidly about a rapidly rotating Earth. In the first few millions of years of the existence of this multiple-satellite system, the larger and gravitationally more powerful Moon attracted many of the lesser bodies with considerable force, so that their impact left the larger scars on the Moon's face. As tidal forces slowed the Earth's rotational speed, the conservation of angular momentum (see page 295) caused the Moon to spiral slowly farther and farther from the Earth and enabled it to pick up more and more of its lesser neighbors, acquiring thus more and more scars and even the great holes out of which poured

the lava that formed the maria.

Still another recent hypothesis declares that the surface of the Moon is subject to erosion from the intense, unshielded radiation from the Sun—radiation kept away from the Earth by its atmosphere. This radiation has decayed the surface material of the Moon into a fine dust that has flowed into the low places on the Moon's surface. This dust may be as much as 2 or 3 miles deep on some parts of the Moon. Because the Moon is airless, this dust is closely packed. Experiments in placing fine dust in a vessel from which the air has been exhausted produce a solid formation with an almost impenetrable surface. If this condition exists on the Moon, the danger of an explorer's sinking out of sight in a quicksand is minimized.

One last theory of the formation of the craters should be mentioned. This hypothesis takes a stand against the impact theory and says that the craters were formed by sluggish eruption on a large scale. Lava from the interior of the Moon in ages past, when the Moon had a molten center much as the Earth does at present, pushed up the surface of the Moon slowly and raised great areas in the form of low bubbles. Then, as the Moon cooled and the lava subsided, the bubbles collapsed, leaving the craters. Probably some combination of impact and eruption will be found to be the answer to the formation of the craters and the maria. There seems to be little doubt that the meteorite impact has accounted for some of the craters, for there are many similar scars on the Earth which we are sure were made by meteor bombardment, and still others are suspected of having been so formed. It is, of course, difficult to make a definite final statement from this distance. When and if geologists ever get a chance to examine the surface of the Moon first hand, the correct answer will probably be forthcoming.

The Moon is the most fascinating and interesting object in the sky for the beginner in astronomy. Its various mark-



**Slow pressure of internal forces pushes up a section of lunar surface but does not break through. When pressure subsides, the dome collapses, leaving a circular hollow.**

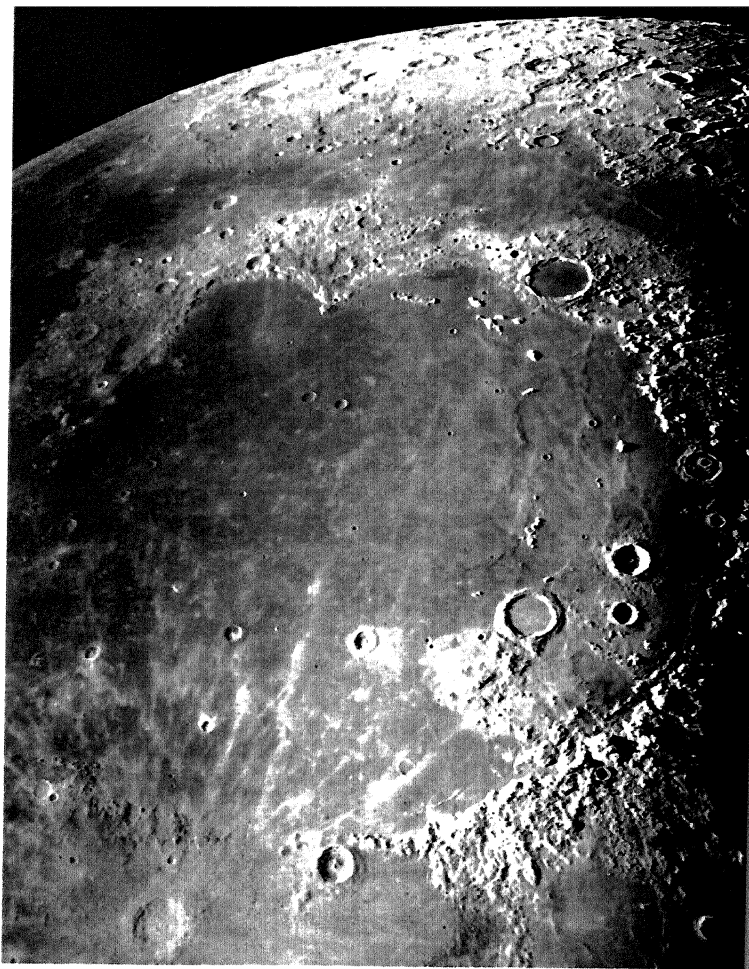
ings can be vaguely seen without any optical aid. Man's imagination has arranged these markings into various images: the man in the Moon, an old lady with a bundle of fagots, a rabbit, a monkey, and other creatures, depending upon the culture and imagination of the beholder. The great dark plains, which are dark because they are less efficient reflectors of light than are the mountainous regions, make, by contrast, the features of whatever one sees.

Many of the thirty thousand markings that can be distinguished on the Moon have been named, and the names are generally given in Latin. The maria have been given romantic or philosophical names; the mountain ranges, for

the most part, have been named for mountain ranges on the Earth; and the craters have been named for individuals. The largest of the maria, lying on the eastern side of the Moon, the side we see at full moon and after, is the Oceanus Procellarum, the Ocean of Storms. It is the Moon's only ocean. North of it is the largest sea on the Moon, the Mare Imbrium, the Sea of Showers. South of the ocean is the Mare Nubium, the Sea of Mists. Very nearly in the center of the Moon's disk is the small Mare Vaporum, the Sea of Vapors. To the west, on the new moon side of the disk, are three fairly large seas: the Mare Serenitatis, the Sea of Serenity; the Mare Tranquilitatis, the Sea of Tranquility; and the Mare Foecunditatis, the Sea of Fertility. Below this last is the still smaller Mare Nectaris, the Nectar Sea; and near the western edge of the disk is the Mare Crisium, the Sea of Crises. Near the northern limb is a long, narrow dark area, the Moon's Arctic Ocean—the Mare Frigoris, the Sea of Cold.

Many indentations protrude from the borders of these seas to form what are called bays or marshes. The best known of these bays, the Sinus Iridum, the Bay of Rainbows, is along the northern side of the Mare Imbrium. The most repellent name on the Moon is the Palus Putredinus, the Swamp of Decay. The persistence of these aquatic names is a sort of monument to the pioneer explorers of the Moon, who saw these dark areas through the first crude telescopes and fell into man's perpetual error of believing their eyes and of likening all celestial bodies to their own Earth. They saw, in their mind's eyes, the dark regions as oceans and seas. When the truth gradually became known to them, the watery names were so familiar and so established that they were not changed, and these imaginary bodies of water remain upon the dry, dead surface of the Moon.

The two most prominent craters on the Moon are Tycho and Copernicus. Tycho was named for Tycho Brahe, the sixteenth-century Danish astronomer whose meticulous measurements of the motions and positions of the stars and planets

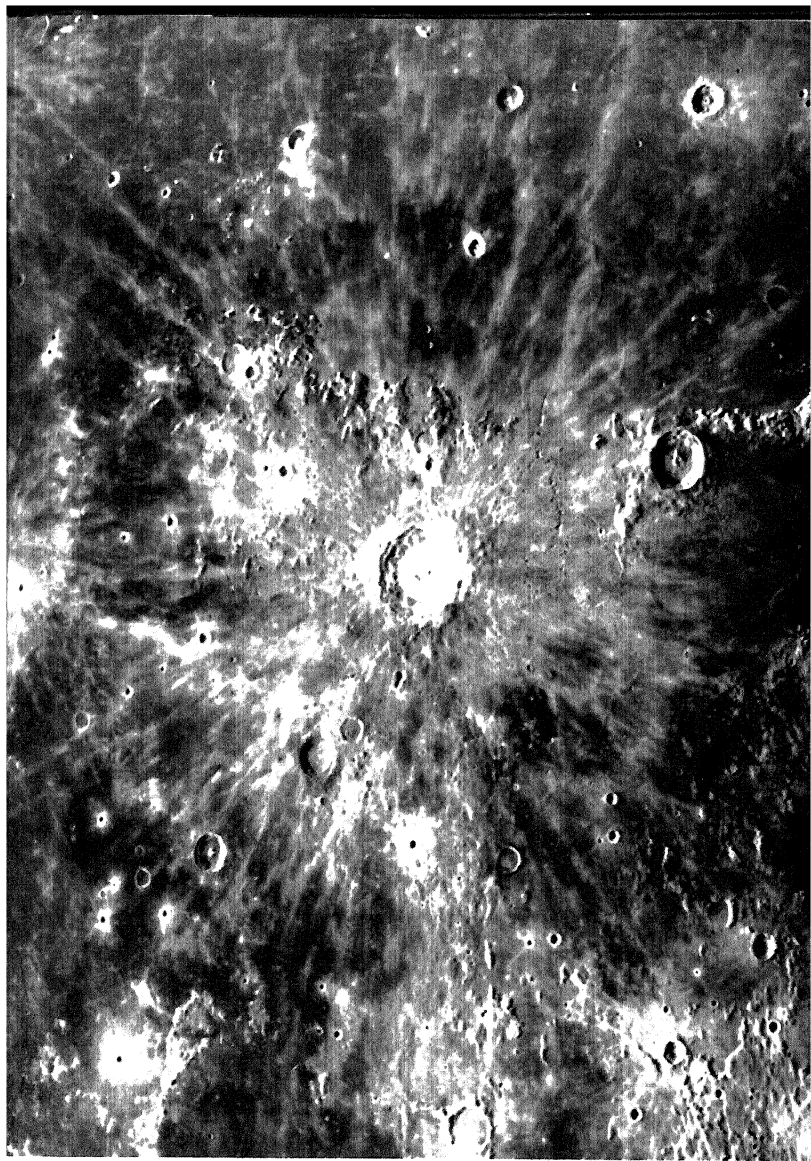


**The Mare Imbrium. Above this large mare stretches the narrow Mare Frigoris. The smooth-floored crater to the northwest is Plato. The isolated mountain range southeast of Plato is the Straight Range. The definite bay east of the Straight Range is the Sinus Iridum. The largest of the three craters below the right center of the picture is Archimedes and the two to the west of it are Autolycus with Aristyllus above it. The curve of the Apennines borders the Mare Imbrium on the southwest and the Caucasus Mountains may be seen to the south. The crater at the eastern end of the Apennines is Eratosthenes.**

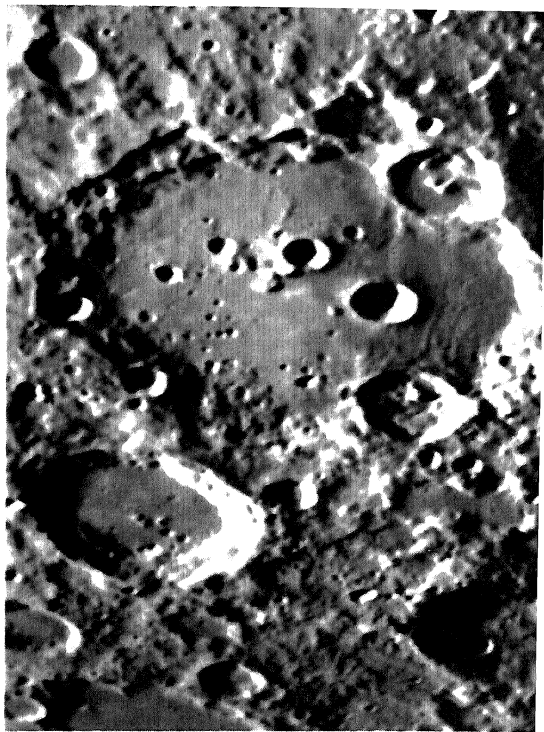
furnished the data necessary to solve the riddle of the mechanics of the solar system. Tycho is in the northwestern quadrant of the Moon's disk and, under good conditions, may be seen as a bright spot with the eye alone. It is a crater about 54 miles in diameter with a double peak in the center of a mountain-ringed plain. The mountain walls surrounding the crater are about 7,000 feet high, as is the central mountain system. The surrounding walls appear to be terraced when seen through a telescope under high magnification, almost as though they had been eroded by diminishing levels of water. Tycho is notable for being the center of a system of bright rays that radiate out from the crater for hundreds of miles, spreading across the lunar surface. These rays may be seen around many of the larger craters on the Moon, and they give strength to the impact theory of crater formation. They have no height, for they cast no shadows, and they pass over peaks and valleys. They do look very much like streaks made by material of a lighter color than the general surface of the Moon which has been ejected from the craters by the crashing force of a meteorite landing. The extreme length of the rays may be explained both by the low surface gravity of the Moon, which would permit the particles composing the rays to travel for great distances before being drawn down to the Moon's surface, and by the lack of atmosphere to offer resistance to their travel as they were thrown up from the surface.

The crater Copernicus is farther east and north, almost in the middle of the boundary between the Oceanus Procellarum and the Mare Imbrium. It has about the same diameter as Tycho, but there is a 12,000-foot peak set in its eastern wall. It, too, is the center of a ray system, which is not as bright as that of Tycho, nor as regular in the length and outline of its rays, but which seems to lie in a roughly circular blotch around the crater. Copernicus is in an area in which several mountain peaks, partly destroyed old craters, and some clefts are to be found.

Far to the south is the largest visible crater on the Moon.



**Copernicus, showing its irregular ray system. West and slightly north of Copernicus is Eratosthenes and above it are the Caucasus Mountains. The three isolated craters across the top of the picture are Timocharis, west; Lambert, center; Euler, east.**



**Clavius, largest of the craters, more than 150 miles in diameter. Below and to the left is Blancanus. The smaller craters inside and on the border of Clavius must be of later formation than Clavius.**

This is Clavius, an irregular walled plain about 154 miles across. It is not prominent because it lies in a rugged region with little level space to offer contrast to the walls of the crater. There are many peaks in these walls that rise to about 17,000 feet, and there are a score of smaller craters inside its boundaries which appear to have been formed after the main crater.

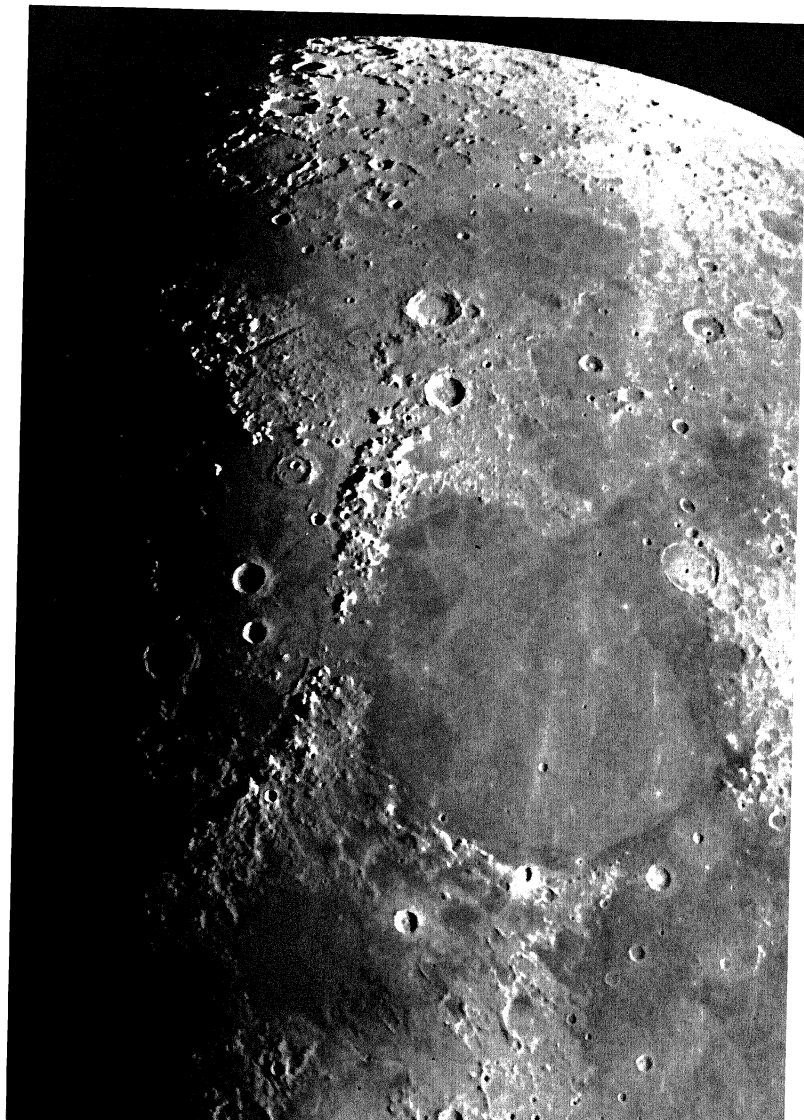
The brightest spot on the Moon is the crater Aristarchus, near the northern edge of the Oceanus Procellarum. Aristarchus is 29 miles in diameter, and its surrounding walls rise



to about 5,000 feet. Owing to some quality of the material inside it or to the angle at which its interior walls are sloped, it reflects sunlight to a greater degree than do any of the other markings on the Moon.

The eastern region of the Mare Imbrium contains several interesting craters. The most prominent of these is Plato, a very dark plain about 60 miles across, to the north of the main part of the mare. Plato appears to be elliptical, but this is probably caused by foreshortening; for as it is on the upper edge of the Moon's visible disk, its northern side is farther from the eye than its southern edge. It is superficially symmetrical and empty, but large telescopes show many tiny craterlets inside it. Below Plato is Archimedes, said to be the most nearly circular of any of the craters. It is about 50 miles in diameter. Near it, to the east, is Autolycus, which is much smaller, but which is one of the deep holes in the Moon. The deepest of all the craters is Newton, which lies near the south pole of the Moon. Newton is small in diameter, but its depth has been estimated to be about 29,000 feet, and its center, at the bottom of this stupendous pit, has never been seen out of shadow.

The Carpathian Mountains lie to the south of Copernicus. Northeast of Copernicus, forming one shore of the Mare Imbrium, are the Apennines. The line that the Apennines originate is carried on to the southeast by the Caucasus Mountains. The western shore of the Mare Imbrium is formed by the Alps, which naturally contain Mont Blanc. Cutting down through the Alps from the Mare Imbrium to the Mare Frigoris is a straight tapering cleft about 80 miles long, which is the Alpine Valley. The Leibnitz Mountains roughen the southern limb of the Moon and contain what appear to be the highest individual peaks upon the Moon. Many of these peaks equal and even surpass the highest mountains of the Earth. Low surface gravity and lack of erosion would allow



**The Mare Serenitatis. The eastern shore of this mare is bordered by the Apennines, coming up from the south and by the Alps, running off to the northeast. The straight gash cutting through the Alps southeast to northwest is the Alpine Valley. The crater west of the Alpine Valley is Aristoteles, and below it is Eudoxus.**

peaks upon the Moon to be thrust to great heights and permit them to remain for countless ages without noticeable change.

There are cliffs on the Moon, notably the Straight Wall, near the western edge of the Mare Nubium. It is about 1,000 feet high and 60 or 70 miles long. Many other cliffs rise above the fairly level spots on the Moon. They are probably the result of a slippage of the rock strata on the Moon, and in the past, moonquakes must have occurred when the stress holding faults of moon rocks in line overcame equilibrium. There are countless other topographical features on the Moon: hills, valleys, mounds, and mysterious formations known as rills. The rills look from the Earth like the eroded beds of rivers that have dried up, but without the possibility of water or of atmospheric erosion, their real nature is unknown.

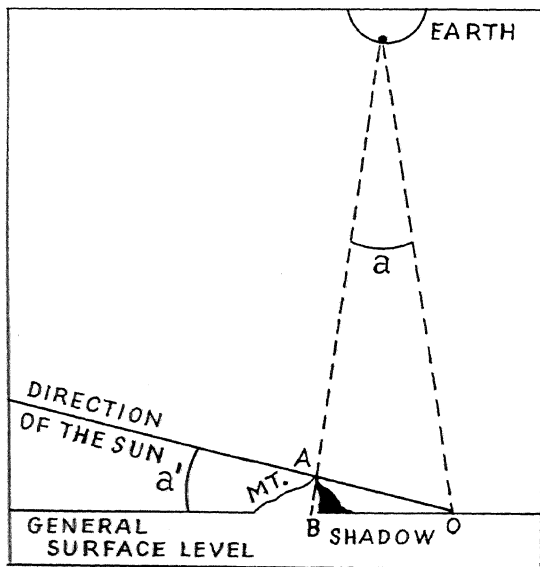
One of the unusual markings on the Moon is Linné, a tiny area in the Mare Serenitatis. Several selenographers have noticed changes in the appearance of Linné through the years, but there has not been any great unanimity in their descriptions of these changes, which seem to have taken place rather slowly. Linné has been reported as a small crater, as a dark crater, as a bright crater, and as having completely vanished. It is possible that the ever-changing angle of sunlight on Linné and on many other of the Moon's markings has given rise to the various interpretations of each.

The measurement of heights and depths on the Moon and of the diameters of the craters is not difficult. If the angle at which the Sun is shining upon the Moon's surface is known, then the length of the shadow cast by a mountain or by the wall of a crater will give the height of the mountain or the crater wall with great accuracy. Since we know the distance of the Moon from the Earth, it is possible for us to tell the dimensions of a feature on the Moon; we know exactly how great a distance in angular measurement is represented by a distance measured on the Moon's surface.

Man must be prepared in certain obvious ways to survive

upon the Moon, such as taking with him his own air and water and insulating himself against the great extremes of temperature that he will encounter there. He must devise some means of protection against the rain of meteorites, and most of all, he must be prepared to encounter hazards of which he has no experience. It is possible that the surface of the Moon may be radioactive to an extent that will prohibit his existence there even for a brief period. He may encounter dangerous chemical combinations which are not possible under terrestrial conditions, lying in wait to eat their way through his protective clothing, destroying its usefulness. In any event, the great adventure of exploring the Moon will involve dangers that have probably never been matched in any terrestrial expedition.

When the direction at which the Sun's rays strike a lunar mountain is known, the height of the mountain may be determined by the shadow it casts.  
Height  $AB = BO \tan \alpha$ .



## The Sun

LET US IMAGINE for a moment that we are capable of standing on the surface of the Sun. Never, for the smallest fraction of a second, is that surface still and at rest. Bright islands of incandescent gas, 300 or 400 miles in their greatest dimension, rise from within the Sun to its surface and remain there for minutes, quivering and shaking. These islands change shape as we watch them, contracting and shifting, their outlines flowing apart here and closing together there. What was an oval becomes an ellipse, then a circle, and then, before we realize it, it has disintegrated and has been replaced by an entirely new island that has slid to the surface from below. Around each of these countless islands of brightness extends a channel of comparative darkness, a lane that changes as the islands change, broadening as they shrink and contracting as they extend. Where two such lanes meet, perhaps at the ends or angles of the islands, an oasis of darkness forms, spreading or shrinking as the islands shift in outline. Such an oasis may grow in size, and as it grows, its edges appear to deepen. These edges take on a definite downward slope and seem to decay outward from the center of the hole, crumbling and spreading until what was only a dark spot is now a shallow depression, deepening into a definite hole. The bright islands bordering the spot disintegrate, and those farther from the edge quiver and shake as if disturbed by

terrible forces. Suddenly, from the edge of the new vastly enlarged hole, a rush of glowing gas hurls itself upward in one continuous surge, pouring outward faster than we can follow and reaching farther than we can see.

All around us other similar outbursts stream from the surface and go lashing upward. Above us clouds form, dissipate, and reform swiftly and continuously, the pace of their change matching the ever-shifting change of the island-studded surface. There is no pause in the turmoil, no peace, no stillness. Not for one second does anything remain in one form or in one place. Far and near, the spoutings continue and the fall of these bright upheavings, as they return to the surface, pour down in one place as a new burst soars swiftly from another. This is a frantic ocean, unbelievably tossed in every direction—up and down and sideways. This is the Sun.

Such a description would probably fit the surface not only of the Sun but of any star with appropriate variations in the speed of the changes that take place and the color and temperature of the materials involved. The Sun is the only star near enough to the Earth for us to form any definite picture of the violent action that must take place upon its surface—if “surface” is the proper word to use for the visible face of the Sun. From Earth, the Sun does seem to have a definite surface: a clean, sharp line marks the edge of the Sun’s disk, even though we know that all the elements in the Sun must be gases. Several different methods of determining the temperature of the surface of the Sun agree that it is about 10,000° Fahrenheit. We do not know of any element that has a freezing point or even a boiling point at so high a figure, so everything of which the Sun is composed must be in the form of a gas. This gas is in a state of tremendous turmoil and upheaval caused by the forces working upon it from the center of the Sun, for deep down beneath the churning, swirling surface there is a temperature of 30,000,000° to 40,000,000°.

Although the density of the Sun is only about one quarter of the average density of the Earth, the central regions of the Sun must be compressed beyond any possible comparison with earthly elements and conditions. The material in the Sun is squeezed infinitely more tightly than the densest metal, but it is nevertheless a gas. At such temperatures, it has to be, in spite of pressure and density.

To possess such an over-all low density with such tremendous pressures in its interior, the Sun must have, at its surface, material of extreme tenuity. The gases there must be almost a vacuum, while those in the center are incredibly compressed. The Sun occupies as much space as 1,300,000 Earths, but a mere 333,000 Earths would contain as much material as does the Sun.

The Sun possesses practically all of the material of the solar system. In this one body is 99.85 per cent of the entire arrangement. Throw away the planets, their thirty-one satellites, the thousands of asteroids, the millions of comets and the billions of meteoroids, all of the atmospheres and minute particles that thread their way in and out between the shifting, weaving solid bodies, and there would still be 999/1000 of the whole concentrated in this one little, second-rate star, the Sun.

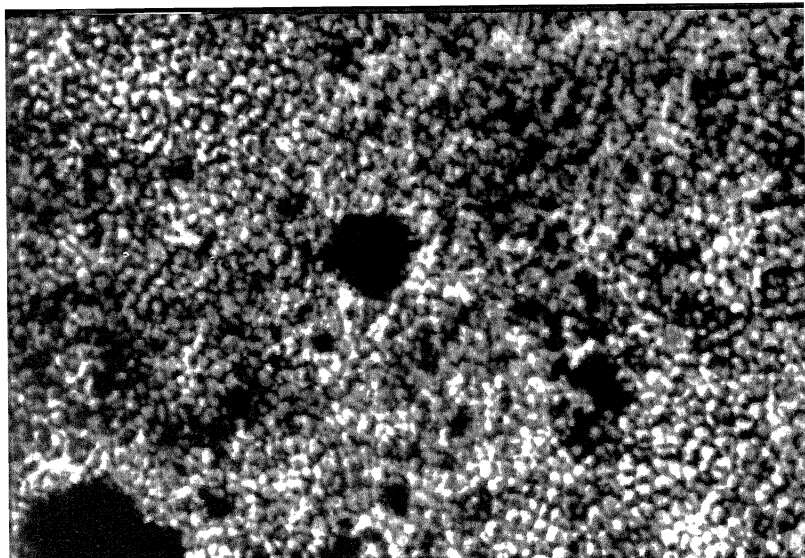
If we take the mass of a body and divide it by the square of the radius of that body, the answer we get will be the surface gravity of the body—the force it exerts to retain objects upon its surface. Gravity is based upon the center of things. Anything that falls upon the Earth is falling toward the center of the Earth and is stopped only because of the accidental interposition of the Earth's surface. Distances between objects in space are measured from the center of one object to the center of the other. To find surface-to-surface distances, we must subtract the radii of the two objects concerned from their center-to-center distances. The greater our distance from an object, the weaker is its gravitational pull. We meas-

ure the surface gravity of the Earth upon ourselves each time we step upon a scale. We translate the surface gravity of the Earth upon our bodies into pounds or kilos or stones.

If we were upon the surface of the Sun, we might expect a tremendous increase in the force of gravity we should feel there, but we must remember the tremendously lesser density of the Sun. It is true that the mass of the Sun is 333,000 times the mass of the Earth, but if we were on the surface of the Sun, we should be much farther from the focal point of the Sun's gravitational power, the center of the Sun. The Sun's diameter is 110 times the diameter of the Earth, so that its surface gravity is only 25 times the surface gravity of the Earth. That is enough to make a man who weighs a comfortable 200 pounds on the Earth sink down upon the Sun, crushed under the burden of lugging around an imposing 3 tons. It is this surface gravity of the Sun that makes the edge of the Sun so neat and incisive, in spite of the fact that it is the edge of a globe of gas. The velocity of escape from the Sun is 384 miles a second.

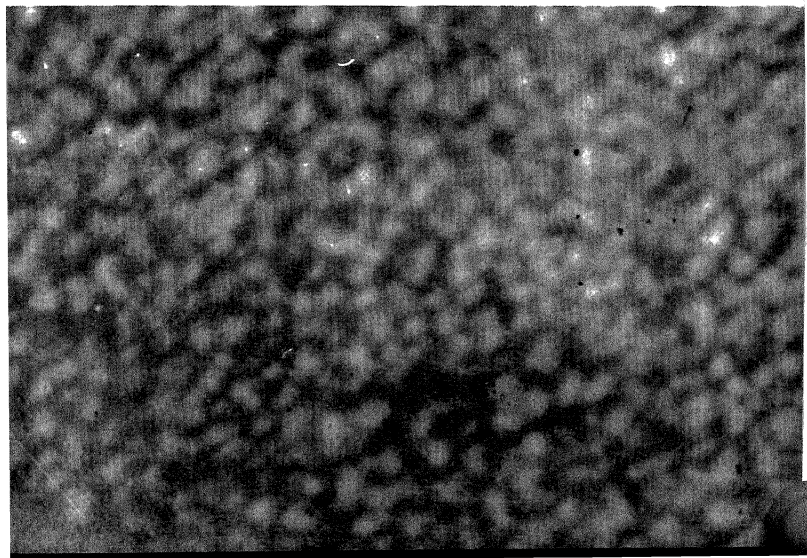
Those islands of brightness that form and disappear on the surface of the Sun are granulations. Each of them is several hundred miles long—or wide—and is roughly elliptical or hexagonal. Two men have succeeded in getting good photographs of them, about seventy-five years apart. In 1885 a French astronomer named Janssen had excellent luck in taking photographs of the Sun, and his pictures stood enlargement so well that they remained the best and most detailed ever taken until 1957. In that year Martin Schwartzschild, of Princeton University, sent a telescope up in a balloon to a height of about 80,000 feet to get above much of the Earth's atmosphere, and tried again. He succeeded remarkably well. His pictures, too, show the granulations and the dark lanes between them. These islands of glowing gas on the Sun resemble those that form on the surface of liquids that are heated from deep down inside, and have been duplicated in





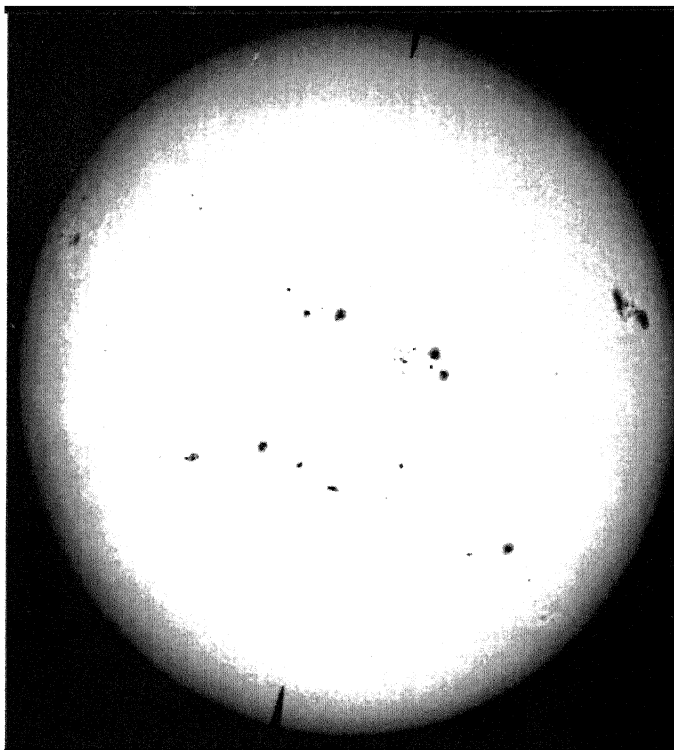
The surface of the Sun showing granulation—"rice grains"—pores and small spots.

Photo of the surface of the Sun in 1957 from a balloon at an altitude of 81,000 feet.



laboratory experiments. The dark lanes between the islands are dark only by contrast, for the islands are intensely and blindingly bright, and the lanes only painfully bright. The islands, in quantity, look like grains of rice swirling and tossing in a saucepan at a rolling boil, and astronomers have named them rice grains. The meetings of the dark lanes—the oases—occasionally grow into definite dark regions called pores, and the pores at times increase in size and prominence into sunspots. Sometimes many bright islands consolidate and combine their forces, making larger bright areas called plages, which is a French word for smooth, broad beaches. The plages were at one time called flocculi, but there are also features on the Sun called faculae—and between flocculi and faculae, something had to give. *Faculae* is a Latin word for “torches,” and the faculae are large brighter patches that appear occasionally where a sunspot has been—something like scar tissue on the Sun. The plages themselves indicate disturbances in the areas where they are found—as if there were ever anything except disturbances on the Sun.

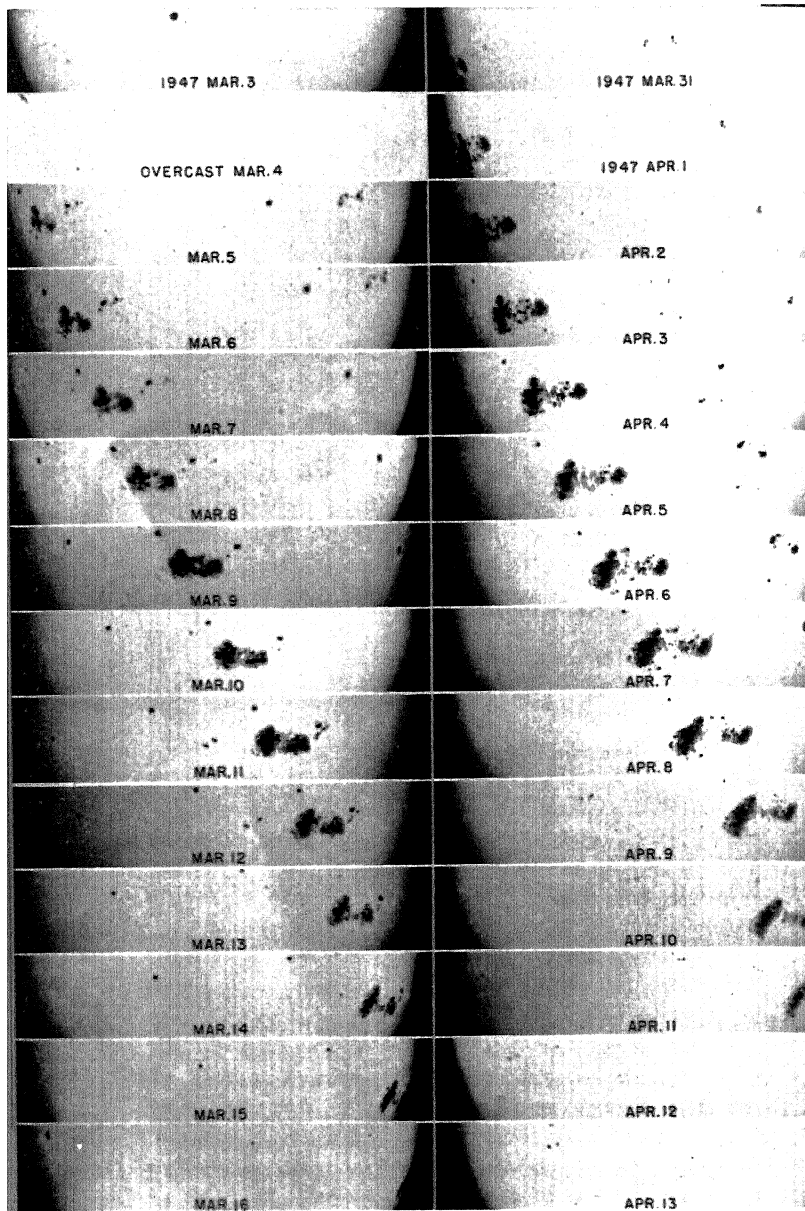
As one of the pores increases in diameter, it also deepens, eating into the surface of the Sun, and the activity around it increases and intensifies until, as a sunspot, it becomes the center of a turbulence of almost unimaginable power. The darkness that is characteristic of the sunspot now spreads out from the center of the spot, gradually shading at the edge and growing brighter until it merges with the brightness of the granulations around it. Around each sunspot focus is an area less dark than the spot and less bright than the general solar surface. This area is the penumbra—the “almost shadow”—by contrast with the dark focus of the spot, the umbra, or “shadow.” There may be many umbrae within one large penumbral area: a scattering of spots, big and little, surrounded by one large, irregular penumbra. The circulation of the gases within a spot is probably spiral, with the edges of the spot producing rising currents while the center is



**The Sun at sunspot maximum.**

descending. Magnetic forces of tremendous strength are formed in sunspots, making each spot an electromagnet whose intensity is thousands of times the intensity of the Earth's entire magnetic field.

Sunspots do not move of themselves through the gases of the Sun. They remain generally in one place, although they are constantly changing in size and intensity. They are carried along by the material of the Sun in which they are embedded, as the Sun rotates upon its axis. It was the apparent travel of sunspots across the disk of the Sun that first told man that the Sun was rotating. Careful timing of sunspot travel has also disclosed the varying rate at which the different parts of the Sun rotate. The Sun is not a solid. As a sphere of gas, it does have certain cohesiveness, but



Series of photographs showing sunspot group carried across the disk of the Sun by solar rotation.

there is a slipping and a shearing between the molecules of gas that would not be possible in the rigid structure of a solid. The broad belt that includes the Sun's equator travels much more rapidly around the solar axis than do the regions near the poles of rotation. At the equator the travel of the spots indicates a velocity that will carry a spot completely around the Sun and back to its starting place in a few hours less than twenty-five days. Halfway between the Sun's equator and its poles, the period of rotation is twenty-seven and a half days, and at the poles it is thirty-four days.

Not all sunspots endure long enough to make the complete trip around the Sun. Logically, the larger spots are the longer-lived, but fewer than 10 per cent last long enough to be carried through one complete rotation of the area in which they are found. Many of the small spots do not even finish a journey across the disk of the Sun. One giant, over a hundred years ago, held out for twenty revolutions and was visible for almost eighteen months.

There are apparently two forbidden areas on the Sun's surface for sunspots. These are the polar regions. Sunspots have never been seen farther than 45 degrees from the solar equator, and very few are ever found within 5 degrees of the equator. The study of sunspots, their timing, their grouping, and their strange periodicity was first undertaken by an amateur astronomer in Germany. Samuel Heinrich Schwabe had a 2-inch telescope through which he observed the Sun in the free time he had while he was running his apothecary shop in Dessau. He observed and made notes and counted and measured, and after twenty years of study he was able to announce that there appeared to be a cycle in the appearance of sunspots. He had seen the spots come, increase, and vanish; he had timed them and found that over the twenty years of his surveillance there had been an average of about ten years between those times when there had been few, if any, sunspots visible.

This period was later found to be uneven and irregular.

Sometimes there would be two minima of sunspot activity at an interval of nine years; at other times fourteen years would pass between two sunspot minima. The average time that elapsed between minima, however, worked out to be very nearly that declared probable by Schwabe. In more than one hundred years of checking since Schwabe's first announcement, the sunspot cycle has been refined to an average interval of 11.2 years between sunspot minima.

In the cases of the times of greatest sunspot activity, the intervals are even less regular. A sunspot maximum may follow a minimum very closely, or it may come soon before the following minimum. There is, furthermore, no regularity in the number of spots at either a maximum or a minimum. The timing of the various sunspot periods and the number of spots or the total area involved in the spottiness cannot be forecast with absolute accuracy. In general, the increase from minimum to maximum is much more rapid than the decrease from maximum to minimum; and during the last few sunspot cycles there seems to have been an increase in the number of spots appearing in each successive maximum over that in the preceding maximum. The maximum of late 1958, the most recent at this writing, produced the greatest sunspot population ever recorded.

There are many days during a sunspot minimum when there are no apparent spots on the disk of the Sun, but, in general, the spots of a new cycle begin to appear even before the last spots of the previous cycle have vanished. The new spots are always farther from the Sun's equator than were the last of the old ones. A few small spots still appear about 30 degrees above or below the solar equator to begin a new cycle. As the cycle progresses, spots appear nearer and nearer the equator, until the last spots of a cycle are breaking the Sun's surface at the edge of the 5-degree line at the same time that the tiny new spots are showing in the higher latitudes.

There is no answer yet for the avoidance by sunspots of the higher latitudes or for their constant descent in latitude as their cycle grows. In fact, the entire makeup of sunspots is, at present, a mystery. One of the strangest puzzles they present is the apparent reversal of their magnetic currents. Spots generally come in groups, and the groups fall, as a rule, into two subgroups. Through the spectroscope, the dark absorption lines observed in sunspots show certain peculiarities that indicate strong magnetic fields. Such magnetic influence splits the dark lines, and an analysis of the lines shows the direction of the flow of the magnetic currents. In sunspots the magnetic current flows in opposite directions in each of the spots of a pair: the flow is in one direction in one of the spots and in the opposite direction in the other. To complicate matters still further, the polarity—the direction of the flow—is reversed in such pairs of spots depending upon whether they are above or below the Sun's equator. If the leading spot of a pair in the northern hemisphere of the Sun shows a negative magnetic flow, the following spot will show a positive flow. At the same time, in the case of a pair of spots in the southern hemisphere, the leader will be positive and the follower negative. It is not always possible to determine the polarity of a sunspot group because the group may be composed of spots individually too small and too confused for their magnetic currents to register well through spectroscopes.

An astronomer named Rudolph Wolf took up the systematic observation of sunspots about where Schwabe left off, and others have since carried on these observations, so that the chain of solar investigation has been unbroken for the last 150 years. Wolf devised a standard of solar activity which he expressed by a number. This is called the sunspot number, and it furnishes an excellent indication of sunspot activity. Each regular solar observing station is given a constant that is determined by the size of the station's telescope.

the average number of good observing days during the year at the station, the number of observations usually made, and so on. This constant is used to modify the number of sunspot groups observed and the number of individual spots in the groups. A particular observatory will have, for example, a constant of 1. This station will observe the Sun and find upon it five groups of spots and will count a total of twenty spots in the five groups. That station will then multiply the group number by 10, add the individual spot count to that figure, and multiply the whole business by its constant of 1. That will come out to  $10 \times 5 + 20 = 70 \times 1 = 70$ , which is the sunspot number. A comparison of many stations, each with its own constant, gives astronomers a day-to-day view of the condition of the Sun, which is extremely valuable in calculating the effects of the sunspot cycles.

All of the phenomena connected with sunspots, together with the granulations, take place on the visible surface of the Sun. This surface is the photosphere, or "sphere of light." It is the photosphere that we refer to when we speak of the surface of the Sun. It is the ultimate source of most of the Sun's light. The photosphere is not deep, but we cannot see through it. It is opaque because it is composed largely of hydrogen whose atoms have acquired one more neutron than there is in the nuclei of ordinary hydrogen atoms. This isotope of hydrogen is not transparent. Beneath the photosphere is the tremendous atomic reactor that produces the energy that pours out of the Sun in a volume that is almost impossible to describe. The effective temperature of the photosphere has been said to be about 10,000° Fahrenheit. In order to produce this temperature in the photosphere, the temperature in the regions below the photosphere, increasing toward the center of the Sun, must finally reach about 35,000,000°.



## THE CARBON CYCLE

How it was possible to produce the amount of energy that poured out of the Sun was a puzzle to mankind for thousands of years. As soon as man began to realize the magnitude of this phenomenon, he began to try to imagine how it was done. If the Sun were made entirely of pure coal that was being burned, it would have been completely consumed in a few thousand years. If the fires of the Sun were being fed by a constant rain of particles that poured in from space, so much material would be needed that all space would have to be filled by the inpouring meteoroids. If a body constructed of a fiercely active gas, as was the Sun, should collapse, a high temperature would result, but the degree of temperature on the Sun would require a collapse so rapid and so continuous that the Sun would have shrunk to insignificance long ago.

By 1938 man had learned enough about the changes that take place inside the atom to be able to dream up some theories about the processes that were creating the energy of the Sun and, indeed, of all the stars. Dr. Hans Bethe, a physicist at Cornell University, fitted together the transformations that were known to occur in atoms at the temperatures that were known to exist inside the Sun. Dr. Bethe's theory was linked to a hypothesis made about thirty years earlier by Albert Einstein. Einstein had suggested that matter and energy were different manifestations of the same force and were interchangeable. He said that if one gram of matter could be completely converted into energy, the resulting force would be equal to the amount of matter multiplied by the square of the speed of energy. He expressed this relation in the equation  $E = MC^2$ . This force would be expressed in ergs, which is the amount of work accomplished in moving a mass of 1 gram through a distance of 1 centimeter in a time of 1 second. A gram is about one thirtieth of an ounce,

and a centimeter is slightly more than one third of an inch. Neither of these amounts is impressive. It is the last factor in the equation that produces the enormous result—the square of the speed of energy, of radiation. The velocity of radiation is 186,000 miles a second in a vacuum. This is 300,000 kilometers a second, or 300,000 million centimeters a second. That figure, squared—multiplied by itself—is a 9 followed by 22 zeros. Multiply the tiny figure of 1 erg by this last imposing factor and it will provide sufficient energy to lift a weight of 7,000,000 tons to a height of a mile above the surface of the earth in one second.

In order to produce the amount of energy that is given off by the Sun every second, 425,000,000 tons of matter must be changed completely into energy according to Einstein's formula. This seems like an enormous amount, but the Sun is an enormous body.

There is one element in the universe whose abundance apparently exceeds by far the abundance of all the other elements combined. This element is hydrogen. Dr. Bethe began by assuming that hydrogen was the basic material whose transformation into energy produced the power of the Sun and of the stars in general. Dr. Bethe also suspected that under certain conditions hydrogen would need help from some other element in accomplishing this transformation. He selected carbon as the possible assisting agent, or catalyst, that would make possible the conversion of hydrogen into energy. It was also known, by this time, that there was a tremendous quantity of helium in the Sun. Indeed, helium had been discovered in the Sun through the agency of the spectroscope many years before it was found upon the Earth. Its very name comes from *helios*, the Greek word for "sun."

In Dr. Bethe's suggested process, a nucleus of the carbon atom, which has a relative weight of 12.1, combines with a hydrogen nucleus, called a proton, to form radioactive nitrogen. Normal nitrogen has a relative weight of 14.01, but the

nitrogen formed by this combination of a proton and a carbon nucleus has a weight of 15 and is therefore called an isotope of nitrogen. It is unstable and produces the first burst of energy in the entire process by ejecting a gamma ray—a bit of high-frequency radiation. This ejection transforms the unstable nitrogen into a carbon nucleus with a relative weight of 13 and releases a positive electron—a positron.

In time, this isotope of carbon encounters a second proton and is transformed into ordinary nitrogen with a relative weight of 14.01; in the encounter a second gamma ray is released. The normal nitrogen nucleus meets a third proton, and the result of this encounter is radioactive oxygen with a relative weight of 15, as compared with normal oxygen with a weight of 16. The unstable oxygen nucleus produces a third gamma ray and becomes a nitrogen nucleus with a weight of 15 and releases another positron. The fourth and last proton involved in this process meets this last isotope of nitrogen and transforms it, in turn, into two nuclei. One of these is carbon, with a relative weight of 12.01, and the second is helium, with a relative weight of 4.003. The net result of this chain of reactions is the destruction of four hydrogen nuclei, the protons with a total weight of 4.030; the formation of a helium nucleus, with a weight of 4.003; and the restoration of the original carbon nucleus whose first encounter with the first proton started off the whole routine. The total loss of mass is the difference between the original weight of the four protons, 4.030, and the weight of the helium nucleus, 4.003—that is, 0.027. This 0.027 has been converted into energy. In this process, sufficient hydrogen and carbon is involved so that the sun loses 425,000,000 tons of hydrogen every second.

This is the carbon-nitrogen cycle, and the transformations involved are possible wherever temperatures are around 16,000,000° Fahrenheit or more. For lower temperatures another process also involving four hydrogen nuclei is sug-

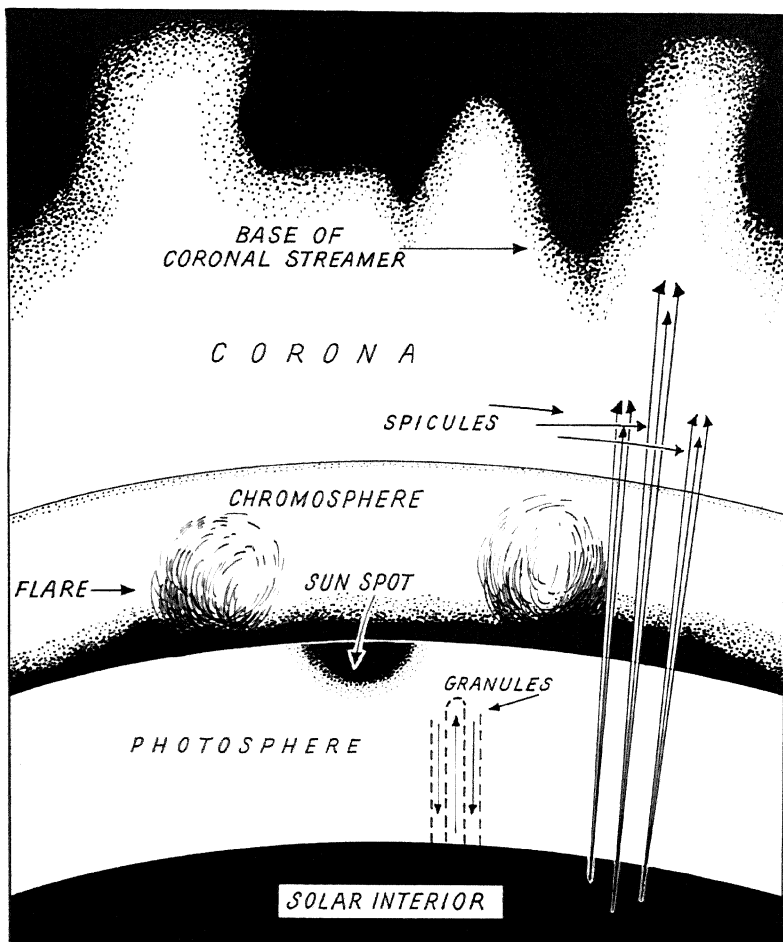
gested. In this latter process—the proton-proton reaction—two protons collide and become the nucleus of an isotope of hydrogen with a relative weight of 2. Such a hydrogen nucleus is called deuterium, or heavy hydrogen, and is found in great abundance in the Sun. In fact, it is this same heavy hydrogen that makes the photosphere so opaque that it is not possible to see into the interior of the Sun. With this first collision of two protons, a positron is released. A third proton now collides with the heavy hydrogen nucleus, transforming it into a still heavier hydrogen nucleus with a relative weight of 3, an isotope of hydrogen known as tritium. This, in turn, meets a helium nucleus with a relative weight of 4 and becomes an unstable variety of beryllium with a relative weight of 7, against the normal weight for beryllium of 9. The isotope of beryllium degenerates into a normal lithium nucleus, with a relative weight of 7, by emitting a second positron. The lithium nucleus is then struck by the last of the four protons involved in this process and is transformed into two helium nuclei. Since one helium nucleus was destroyed, the net result is about the same as in the carbon cycle: four protons have been consumed, and one helium nucleus remains, with the same slight loss of mass, which has been transformed into energy. One or the other of these processes is believed to be taking place in all stars with differences of detail depending upon the amount of hydrogen—the basic material—available and the temperature at the interior of the star.

With the Sun's interior a seething mass of atoms that have been deprived of most, if not all, of their electrons and that are in a state of terrific turmoil, it is small wonder that the surface of the Sun reflects some measure of the activity going on beneath it. The energy produced by the complicated process we have just outlined reaches the surface of the Sun, from which some of it escapes by radiation. The power of this radiation is always in a contest with the more stable and

steadier force of gravitation, and the Sun is, as a consequence of this unending struggle, held together as one body. The passage of radiation outward from the Sun is probably responsible for the depth of the two outer shells of gas that enclose the photosphere and may be considered as the atmosphere of the Sun. If it were not for the fierce radiation from the interior, these shells would be, at the most, about 600 miles deep. As it is, their total extent into space around the Sun is measured in millions of miles.

The first of the two layers of solar atmosphere above the photosphere is the chromosphere, so called because of its intense pink color; the word chromosphere means "sphere of color." The chromosphere is thousands of miles deep, but it is considerably less dense than the central portion of the Sun or than the photosphere. It follows the pattern of atmospheres by decreasing in density as the distance above the photosphere increases. The lowest few hundred miles of the chromosphere is sometimes considered as a separate layer of atmosphere, distinct from the higher levels, and is called the reversing layer. This lowest region is the most dense part of the chromosphere and receives its name from the effect it has upon the spectral lines that are the visible manifestation of the Sun's energy. The gases in the reversing layer of the chromosphere absorb much of the radiant energy from the body of the Sun and transform the bright lines in the spectrum that would normally be produced by elements reacting at the fierce temperatures that exist inside the Sun, into dark lines that have identical locations in the spectrum as the bright lines would have had. Thus, this reversal from bright to dark—from emission lines to absorption lines—gives this part of the chromosphere its name.

Above or outside the reversing layer, without definite division, is the main part of the chromosphere, in which many of the visible results of the Sun's power are seen. The chromosphere is to a large extent transparent, although it does



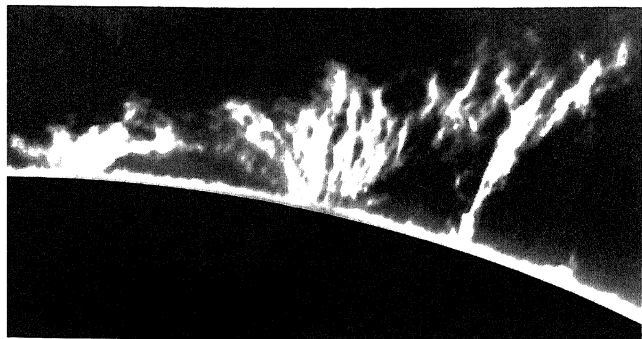
**Cross-section of the Sun's atmosphere.**

reduce the light of the photosphere considerably. The chromosphere cannot be seen under ordinary circumstances, but it is visible only when the photosphere is covered. This happens in nature only during a total eclipse of the Sun, when for a few minutes the Moon passes so directly between the Sun and the Earth that it blots out the photosphere, permitting the chromosphere to be seen. In 1930 Bertrand Lyot, a

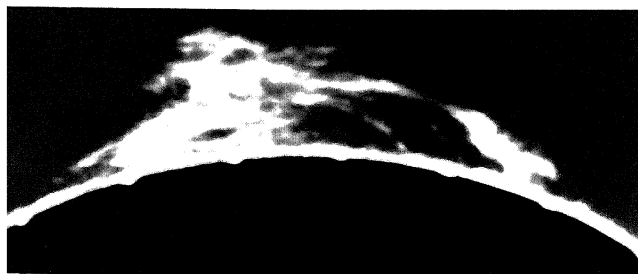
great French astronomer, invented the coronagraph, which is essentially a telescope equipped with a disk that covers the photosphere, and which contains other apparatus for eliminating direct sunlight. With the coronagraph, the chromosphere can be seen at any time in which the Sun itself is visible, and it will even permit the taking of motion pictures of the tremendous activity of the chromosphere.

This activity consists, for the most part, of tremendous, rapidly moving clouds of hydrogen that are called prominences. The motion of the majority of the prominences seems to be downward toward the Sun from clouds far out in space above the surface of the Sun. There are, however, many prominences that obviously originate in the body of the Sun and are expelled outward, and these seem to be the more spectacular of the two varieties. Scientists have separated the prominences into classes according to their appearance and behavior. The most common type is made up of prominences that appear to form in space outside the Sun and to rain down upon it. They seem to be twisting filaments interlacing with each other as they descend. These are called active prominences. The eruptive prominences rise from the upper surface of the chromosphere and speed out into space, sometimes reaching tremendous velocities and heights before they fade away. The record speed for eruptive prominences has been measured at 450 miles a second. The greatest heights reached by them have been in excess of a million miles—more than one Sun diameter.

Some of the prominences are directly associated with sunspots and are called sunspot prominences. They assume a number of different forms, and many resemble fountains, spraying up and falling back. There are prominences that look like twisted columns and are called tornado prominences. The quiescent prominences are the least active and are, consequently, those with the longest lives. They resemble clouds in being more massive and cohesive than most promi-

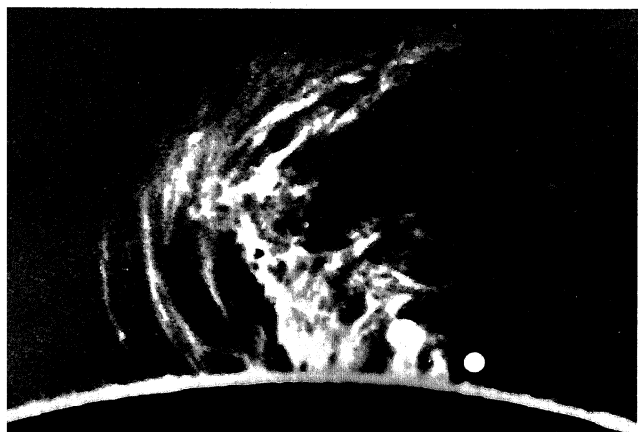


Solar prominence; height about 80,000 miles.

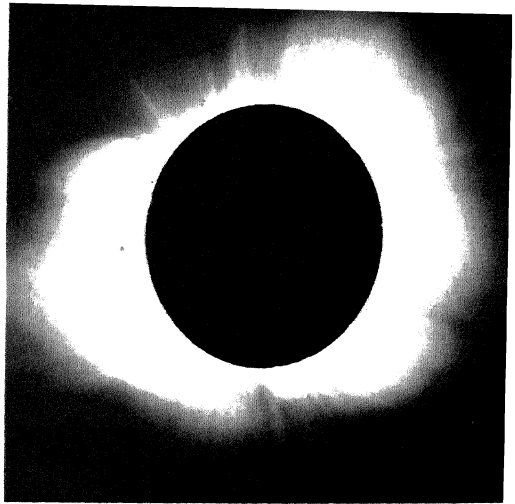


Solar prominence; height about 130,000 miles.

Large active prominence, 140,000 miles high.  
The white dot shows size of Earth.



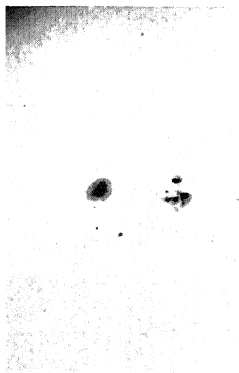




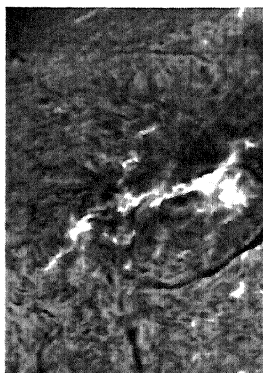
**Solar corona showing spicules at poles of Sun.**

nences. The commonest variety of quiescent prominence is called the haystack and resembles that farmyard storage heap in general outline. Finally, there are long, slender streamers coming down from the corona, the outermost layer of solar atmosphere. These coronal prominences are short-lived and seem to pour down like single spouts of rain. In addition to these definite prominences, there are also short, slender outshoots from the polar regions which rise rapidly and last for only a few minutes. These last are spicules. With the exception of the spicules, the prominences are tremendous in the scope of their travel, often reaching their maximum heights and dimensions in a matter of hours.

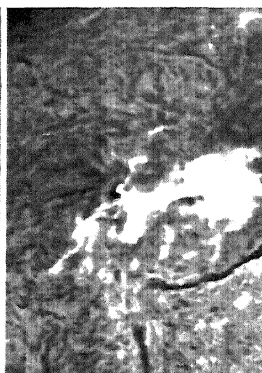
Much shorter-lived, less spectacular in appearance, but much more intense than prominences are solar flares. These usually appear from regions bordering sunspot groups, become intensely bright, and last, as a rule, about an hour or so. Flares, while generally smaller than prominences, grow much brighter and seem to possess an almost fierce aspect during their relatively short lives. They will rise suddenly to heights of about 30,000 or 40,000 miles and remain there for some time before subsiding more slowly back into the



Direct photograph of  
a group of sunspots on  
August 8, 1937, at 5<sup>h</sup>44<sup>m</sup> P.S.T.



The same region photographed  
in the red light of hydrogen  
at 5<sup>h</sup>55<sup>m</sup> P.S.T.



The same region showing a  
flare at maximum intensity  
at 6<sup>h</sup>06<sup>m</sup> P.S.T.

**Rapid development of solar flare is shown in photographs taken about 15 minutes apart.**

chromosphere. The energy accompanying flares is most often associated with disturbances in the Earth's ionosphere, when radio communication is often disrupted and the auroral activity is intensified. Such manifestations occur, as a rule, three or four days after the appearance of a flare and may be caused by the ejection of particles from the Sun during flare activity which travel swiftly to the Earth and are absorbed by the ionosphere. Flares seem to be composed principally of hydrogen, and, indeed, hydrogen has always been present in them even though other elements are also found.

Outside the chromosphere lies the corona, and it, too, is not visible under ordinary circumstances. It can be seen during a total eclipse and, to a lesser extent, by means of the coronagraph. During an eclipse the corona is seen to extend outward irregularly from the Sun to tremendous distances. Its color is generally a pearly white with a slight tinge of yellow near the Sun. The corona produces about half as much light as the full Moon, or about one millionth the light of the Sun.

The corona appears as a delicately diffuse cloud with slender streamers extending outward away from the Sun

through it. Its outline is not stable, varying with changes in the sunspot cycle. At times of sunspot minima the corona is extended much farther out into space over the equatorial region of the Sun than above its poles. At sunspot maxima the corona is generally more evenly circular in cross-section about the disk of the Sun and extends much farther from the Sun than during sunspot minima. The corona can be observed to some extent at any time by means of the coronagraph, but it is still largely in the realm of the unknown.

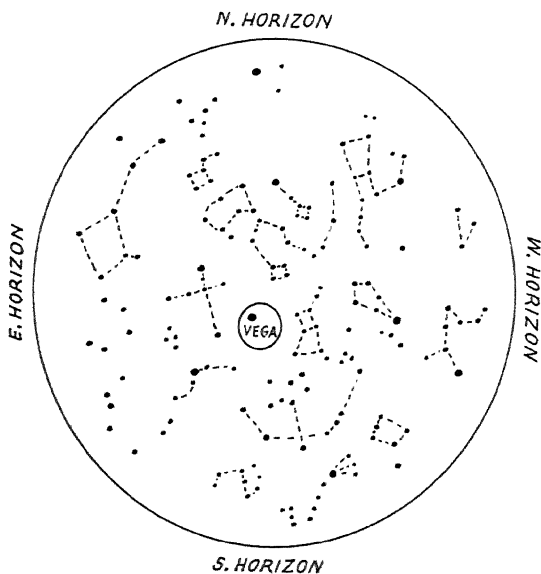
It is only within recent years that astronomy has been able to observe spectral lines from the corona that were definite enough to tell us something about its condition. Even here a frustrating mystery developed. Certain lines in the first successful spectrum of the corona could not be identified as having been caused by any element known on Earth. The apparently new element was hailed as a great discovery and given the name of coronium. Not too many years ago, however, coronium was revealed to be an impostor. The lines in the spectrum that seemed to indicate a new element were found to be lines belonging to old, familiar friends, such as iron, nickel, and calcium, which had been exposed to radiation more fierce than man had ever imagined. Radiation of such force ripped more electrons from about the nuclei of these common atoms than had ever been thought possible, and caused them to produce the strange spectral lines. Coronium turned out to be common elements in states such as had never been witnessed. These elements were in a condition that could be produced only by a temperature of about 1,000,000° Fahrenheit, and yet these lines were far outside of the central body of the Sun, where such temperatures are common. Thus, in spite of the fact that the general temperatures of the visible surface of the Sun, the photosphere, and the chromosphere can be measured in mere thousands of degrees, the temperature in regions of the corona as far as a million miles from the surface of the Sun rises to about

1,000,000°. The smoke of the bonfire is hotter than the bonfire.

Some of the chief problems of astronomy stem from the fact that everything in space is in motion and that these motions are exceedingly complex. The sun, like all the stars, is not only rotating upon its own axis, but it is traveling through space, carrying with it a retinue of captive planets, satellites, asteroids, comets, and meteoroids. The Sun is a member of that vast assemblage of stars called the Local Galaxy, and as such, it is swinging around a point in the center of the galaxy with a velocity of about 150 miles a second. In addition to this motion, it is threading its way among the other stars of the galaxy with a velocity of about  $12\frac{1}{2}$  miles a second. Its target on this last evolution is a point near the eastern edge of the constellation of Hercules, near the border of Lyra. This goal is called the apex of the Sun's way.

The location of the point toward which the Sun is travel-

**The apex of the Sun's way lies in the small circle.**



ing was discovered by Sir William Herschel in the course of a massive survey of the stars, on which he spent many profitable years. Herschel stated that he observed every object in space within the reach of his telescopes, which were far better than the average instruments of his time. He checked star positions and magnitudes with the most meticulous care and found that the stars in that part of the sky toward the eastern edge of Hercules seemed to be moving away from each other with a puzzling consistency. He came to the conclusion that this motion was apparent rather than real and that it was caused by the constant approach of the Sun toward this part of space. If the Sun's motion were the reason for the apparent opening out of the stars, he reasoned, then there should be a reversal of this condition on the other side of the star sphere, at the place from which the Sun must be receding. Herschel's son, Sir John Herschel, went to South Africa to study the skies visible from that part of the world and found the antapex of the Sun's way, a place in which the stars seemed to be moving together. This point is diametrically opposite to the apex and is in the constellation of Columba, which can be seen in winter near the southern horizon by an observer in the middle north latitudes.

Man's growing acquaintance with the stars has led to the conclusion that the Sun is a typical star. In all the ways of classifying stars—temperature, size, mass, brightness, and so on—the Sun always comes near the middle of the group. It is John Doe, the average individual, and belongs to an exceedingly numerous class of stars. To us, it is, of course, the most important of stars. The energy of the Sun helps to keep us alive. It is true that this same energy would kill us all with merciful speed if we were not shielded from it by the Earth's atmosphere. The radiation of the Sun can be measured and is fantastically powerful by terrestrial standards. Every square yard of the surface of the Sun produces 70,000 horsepower. The total horsepower manufactured by the Sun

is expressed by a figure 5 followed by 20 zeros. If a bit of the Sun the size of the head of a pin could be isolated and brought to within a few thousand miles of the Earth, the energy streaming from it would blast any of our great cities out of existence in a fraction of a second.

This tremendous energy goes out from the Sun in all directions. The Earth, a tiny body, intercepts a tiny fraction of the Sun's energy—about one part in two billion. This small share, however, is sufficient to provide every square mile of the Earth's surface with 4,690,000 horsepower. There is no source of energy that man uses that does not stem ultimately from the Sun. The coal and the oil he burns are the decomposed corpses of organic substances that once lived upon the surface of the Earth, soaking up sunlight. The water whose falling turns wheels and turbines to give man power was lifted to the heights from which it falls by evaporation. The vegetables man eats stored up the energy they give him from growing in sunlight. The meat on man's table contains energy derived from grass and grains grown in sunlight and eaten by the animals whose flesh is man's food.

As we see the Sun, it is intolerably bright. We cannot look at it unless it is veiled by clouds or unless we put some sort of protective shield before our eyes. The Sun is four hundred thousand times as bright as the full moon and as bright as six million of the brightest stars. This brightness, however, is due to the nearness of the Sun to the Earth. If the Sun were to be moved to the standard arbitrary distance at which stars are theoretically placed in order to compare their brilliance, it would be just visible to us on a clear night.

As we see the Sun from our northern hemisphere, it rises from the eastern horizon, to our left as we face south, moves across to our right, and is hidden behind the western horizon at the end of the day. The times of its appearance, the arc of its crossing, and the time of its disappearance are governed

by the motions and positions of the Earth on which we live. The Sun is rotating on its own axis from our left to our right as we watch it, and we do not always see the Sun at the same angle. The ecliptic does not lie directly in line with the Sun's equator, but is inclined to that equator by 7 degrees 15 minutes. In January, when the Earth is in that part of its orbit nearest the Sun, we are facing the lower hemisphere of the Sun, and we can see then the south pole of the Sun's axis. In June the Earth has moved until it is in line with the Sun's equator. From June to December the Earth is above the upper hemisphere of the Sun, and it moves across the Sun's equator again in December.

The energy that streams from the Sun drives before it countless subatomic particles, of which the Earth receives a small share. Most of these particles are captured by the Earth's atmosphere, and the impact of their arrival in that atmosphere often manifests itself in perceptible ways. During periods of intense solar activity, when the rain of particles is usually heavier than average, particles from the Sun strike the atoms in the upper levels of the atmosphere with sufficient force and frequency to excite those particles into visibility, causing the colorful, shimmering lights that are the aurorae. The aurorae are most vivid above the Arctic and Antarctic Circles because they are guided to the poles by the lines of force of the Earth's magnetic field.

Although the Sun is a fascinating object for observation, it is also dangerous. No attempt should be made by the amateur to observe it through any sort of optical instrument. Field glasses and telescopes magnify the Sun's energy as well as its appearance, and the impact of the focused power of the Sun through the most moderate of telescopes is sufficient to blind the beholder forever. If you have a telescope, hold a piece of white cardboard before the eyepiece, so that the image of the Sun is projected upon it through the eyepiece.



**The aurora borealis.**

A semiopaque screen mounted behind the eyepiece with the Sun's image thrown against it and seen from beyond the screen is safe. Do not trust welder's glass or optical filters. Glass can crack and permit damage to the eye before the eye can be withdrawn, and only professionals should employ filters.

The Sun, then, is the only star whose surface we can see. All other stars lie at such distances that no telescope we can possibly devise will reveal of them more than a point of light without dimension. From a study of this starlight and from



a comparison of the results of such study with the visible Sun, we have come to the conclusion that other stars perform basically as does the Sun, with differences in detail according to differences in physical composition and in temperature. To us who live as captives in its life-giving energy, this small, second-rate star is the most important in the universe.

## Mercury

MERCURY IS the smallest of the nine planets and is the first planet in order of distance from the Sun. Although Mercury is not easy to see, for reasons that will become apparent later, it was known to the ancients, who named it from the obvious swiftness of its motion and the consequent rapidity with which it changed its position in the sky. The original Mercury was the messenger of the gods and is usually pictured as wearing a winged helmet and winged sandals and carrying a caduceus—a rod about which two serpents are twisted. This is customarily the extent of Mercury's baggage, and it is difficult to understand how he maintained the second of his official positions with so little opportunity for concealment, for Mercury was also the patron of thieves and liars.

As Mercury travels in its path about the Sun inside the orbit of the Earth, its motion makes it seem to swing first to one side of the Sun and then to the other, disappearing twice, for short intervals, during each of its revolutions. Mercury vanishes once because it is between the Sun and the Earth, and it is hopeless to try to see it then, except on rare occasions which will be touched upon later. It disappears the second time because it is beyond the Sun as we see it. In the early stages of man's observation Mercury was thought to be two planets and was given two names, one for each of its manifestations. When the planet appeared in the evening,

setting soon after the Sun, it was called Apollo, and in its morning appearance to the west of the Sun, it was called Mercury. When it became evident that only one object was involved, the name of Apollo was dropped.

Mercury's year, the period of time required for Mercury to complete its revolution about the Sun, is the shortest of any of the planets, and its speed in its orbit is the greatest of all the planets. Mercury's orbit has the greatest eccentricity of all planetary orbits; that is, the shape of its orbit departs farthest from the circular.

Mercury completes its journey about the Sun in 88 days, but because of the combined motions of Mercury and the Earth, it appears in the same position in the sky at intervals of 116 days. The shorter period, which represents Mercury's return to its original position in relation to the Sun and the stars as it is seen from the Earth, is called its sidereal revolution. The longer of the two periods of revolution is Mercury's synodic revolution. "Synodic" is of Greek ancestry and means "by the same road," referring to the return of Mercury and the Earth to the same relative positions with regard to each other. Because its orbit is so eccentric, Mercury's distance from the Sun and its speed during its journey around the Sun vary widely. At perihelion, when Mercury is at that point in its orbit where it is nearest the Sun, they are slightly more than 29,000,000 miles apart, while at aphelion, when Mercury is farthest from the Sun, it has swung out to a distance of 43,000,000 miles. The mean distance between Mercury and the Sun—halfway between these two extremes—is 38,000,000 miles.

In accordance with the laws that regulate the motions and speeds of planets in orbit about the Sun, Mercury must travel much more rapidly when it is passing its perihelion point than when it is at aphelion. Its velocity at perihelion is almost 35 miles a second, but it slows down almost to 29 miles a second at aphelion. These are extremely high veloci-

ties for a planet, and they have given rise to some interesting complications. These widely varying velocities also cause considerable inequality in the periods of time during which Mercury may be seen from the Earth.

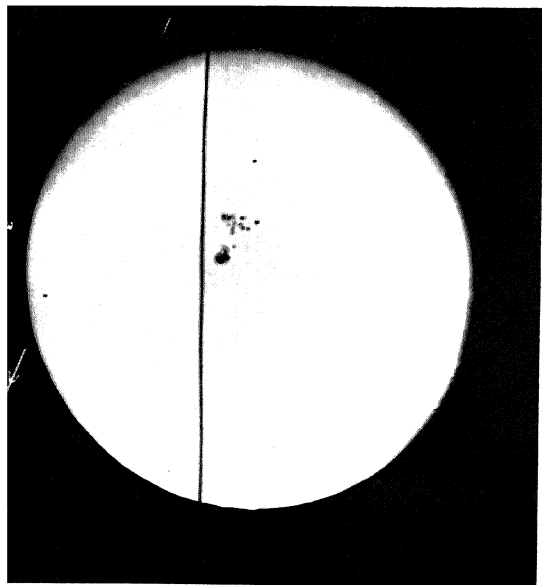
Under favorable circumstances Mercury is visible when it is farthest to one side or the other of the Sun, from our terrestrial point of view. These wide swings are called elongations. Mercury's greatest eastern elongation brings it to the east of the Sun, when it may possibly be seen over the western horizon shortly after sunset, while its greatest western elongation makes it a morning object, seen just before sunrise. The angular distance between the Sun and Mercury—that is, the distance to one side or the other of the Sun at which Mercury seems to be—depends upon the part of its orbit that Mercury happens to be occupying at the time. Not all of the elongations are favorable. If Mercury is at or near its perihelion, it can never appear more than 18 degrees wide of the Sun. This is only about one fifth of the distance from the horizon to the overhead point. Even when Mercury is at aphelion, its angle from the Sun is 28 degrees, or less than one third of that distance. Twilight officially begins in the morning when the Sun has reached a point 18 degrees below the eastern horizon, and evening twilight ends when the Sun has traveled the same distance below the western horizon. It is obvious, then, that Mercury is seldom in the sky during complete darkness. At best, it can only be above the horizon for about half an hour before morning twilight begins or after evening twilight has ended.

Because of its position near one or the other of the horizons, Mercury is always seen through thousands of miles of the densest layer of the atmosphere, along the surface of the Earth. The density of this part of the atmosphere and its turbulence effectively obscure the surface of Mercury and often cause it to twinkle from the effect of air currents on its light. For that reason most of the observational study of

Mercury that has been at all productive has been made in broad daylight through telescopes that could be accurately trained on Mercury's known position. The planet's disk, under such circumstances, would not be distorted and broken up as it would appear to be when seen near the horizon, because there would not be so great an extent of dense atmosphere through which its light would have to pass, but Mercury's face would be considerably paled by the light of the Sun, much like the disk of the Moon seen in full daylight. That is why so little is known of any surface features that Mercury may possess.

It will help us to understand the appearances and disappearances of Mercury if we go along with it on one journey around the Sun. A good place to begin will be at the moment when Mercury has reached its greatest eastern elongation, when it can best be seen in the western sky after sunset. For a few nights it will be visible, but it is constantly drawing more and more into line with the Sun and setting each night a shorter time after sunset. Soon it will be lost in the glare of the Sun as it passes between the Sun and the Earth at the point in its orbit called inferior conjunction. Thereafter, it will draw away from the Sun and will begin to appear in the east before sunrise, rising earlier and earlier each morning until it reaches its greatest western elongation. Between its greatest eastern elongation and its greatest western elongation, a period of forty-four days will elapse.

After its greatest western elongation Mercury will move more and more into line with the Sun again, rising later each morning until it is finally hidden behind the Sun in superior conjunction. Once it has swung past the Sun, it will begin to appear in the evening again, soon after sunset. It will gradually move farther to one side of the Sun, setting later and later until it returns to the point from which it started, its greatest eastern elongation. Mercury begins to be visible from the Earth about ten days or two weeks before its greatest



**Transit of Mercury, November 11, 1907. Mercury is the tiny dot between the two white arrows.**

elongations and remains in sight for six or seven days after those critical periods, either in the east or in the west.

This general picture of Mercury's speeding around the Sun is complicated by a number of minor inequalities caused by the eccentricity of Mercury's orbit and by the fact that the plane of its orbit is inclined at an angle of 7 degrees to the ecliptic, the plane of the orbit of the Earth. This inclination makes Mercury cross the plane of the Earth's orbit at two points, called nodes, each time it makes one revolution about the Sun. On a large majority of the occasions that Mercury passes between the Earth and the Sun, it does not happen to be at either of its nodes, and its passage is, therefore, either above or below the disk of the Sun. If, however, inferior conjunction should occur on Mercury's line of nodes, when Mercury is crossing the plane of the Earth's orbit, there will be a transit of Mercury. A transit is the passage of an inferior planet—either Mercury or Venus—so directly between the Earth and the Sun that from the Earth the planet may

be seen silhouetted against the Sun.

The transits of Mercury take place at intervals of thirteen, seven, ten, and three years. The line of nodes of Mercury's orbit is so situated that Mercury reaches its intersection with the orbit on either the seventh of May or the ninth of November. When transits of Mercury do occur, they must take place on or near one of these dates.

In May, Mercury is at its descending node—it is passing through the plane of the Earth's orbit from above to below—and it is also near aphelion, when it is farthest from the Sun and nearest the Earth. Because of its proximity to the Earth, the apparent diameter of Mercury's disk will be at its largest—about 12 seconds of arc. The apparent diameter of the Sun is about 30 minutes of arc, so that in May transits Mercury will appear against the disk of the Sun as a black speck less than  $\frac{1}{150}$  of the Sun's apparent diameter. Because of Mercury's greater distance from the Sun at these times, however, the portion of its orbit over which Mercury must pass in order to be seen against the disk of the Sun is small, reducing the chances for a transit.

In November the situation is exactly the opposite. Mercury is then at perihelion and is nearest the Sun and farthest from the Earth. Its disk at this time has an apparent diameter of only 9.8 seconds of arc, or about  $\frac{1}{180}$  of the apparent diameter of the Sun, but the part of Mercury's orbit over which it must travel to cause a transit is much longer than in May. The November transits are more frequent than the May transits in the proportion of about 7 to 3. The duration of any of the transits will vary, depending upon the length of the chord of Mercury's passage before the Sun. If Mercury were to move across the diameter of the Sun, the passage could take about nine hours. If Mercury were to cut across the Sun at a tangent to the Sun's disk, the transit could be accomplished in a few minutes. Sometimes Mercury will seem to roll along the edge of the Sun, just brushing the disk,

and no real transit takes place.

The dates of transits of Mercury during the last half of this century are:

|                   |                  |                   |
|-------------------|------------------|-------------------|
| November 12, 1953 | May 9, 1970      | November 12, 1986 |
| November 7, 1960  | November 9, 1973 | November 14, 1999 |

Because of the small diameter of Mercury's silhouette during transits, these events can be witnessed only through telescopes. The usual precautions against looking at the Sun should always be observed at such times. It is best not to put too much reliance on filters of any kind, but to project the image of the Sun upon a piece of white cardboard or on a screen attached to the telescope above the eyepiece. In observing a transit, do not be fooled by sunspots. If the little black speck that you see does not move across the Sun, it is a sunspot.

At times other than transits Mercury will appear as some form of a crescent. It may be glimpsed in nearly full phase when it is at or near superior conjunction. Its apparent diameter will be the smaller the nearer it is to full phase because when it is full, it must be beyond the Sun, at or near its greatest possible distance from the Earth. Wherever Mercury may be, it must always be observed under adverse conditions, either in twilight, dancing and twinkling from the effects of the Earth's atmosphere, or pale and wan in full daylight. Such surface markings as there are on Mercury are difficult to see because of the small apparent size of the planet and because of the circumstances under which it must be viewed. Early telescopic observers tried to estimate Mercury's rate of rotation by the shift of these faintly seen markings. They came up at first with a rotation period for Mercury of 24 hours 50 seconds, and this figure was accepted for many years. At the same time it was taken for granted, again from the apparent motion of the surface markings, that the pole of rotation of Mercury was inclined at an angle of about 20



degrees from the plane of its orbit about the Sun.

These estimates of Mercury's rotation and inclination were abandoned in 1891, however, through careful observations by Dr. G. V. Schiaparelli, the same astronomer whose report on Mars some years earlier gave rise to the great Martian canal furor, which has not completely subsided to this day. Schiaparelli found, after a series of observations of great accuracy, that Mercury rotated only once on its own axis as it made one revolution about the Sun. As a result of this combination of motions, Mercury steadfastly keeps the same face turned toward the Sun, just as the Moon always keeps the same face turned toward the Earth, and for a similar reason. Also, as in the case with the Moon, the steady rate of Mercury's rotation, contrasted with its widely varying orbit and velocity, give Mercury a large libration—an apparent rocking from side to side in relation to the Sun. Mercury's libration is so great that the surface of the planet swings back and forth through an arc of  $23^{\circ}.7$  in longitude as seen from the Sun. Because of this libration the faint markings on the surface of Mercury appear to occupy different positions in relation to the line that divides light from dark on the surface of the planet—its terminator. It was this shifting of surface markings that gave rise to the early error in the estimate of the speed of Mercury's rotation. Schiaparelli's estimate of a rotational period of eighty-eight days has often been confirmed since he first made it. This confirmation, however, does not extend to the inclination of Mercury's axis of rotation. Although no one has yet been able to pinpoint the angle at which Mercury stands to the plane of its revolution, it is generally accepted that this angle is very small and that, for all intents and purposes, Mercury marches erect about the Sun.

The surface of Mercury has, in general, a bright yellow appearance. Some grayish markings are visible, and there are localized areas so bright as to appear almost white. Certain

surface irregularities cause strange shadows to mar the even curve of the terminator of Mercury, sometimes cutting the sharp end completely off its southern tip when it is seen in crescent form. From the meager evidence available, it appears that the surface of Mercury closely resembles the surface of the Moon. This theory is strengthened by the fact that both Mercury and the Moon reflect exactly the same percentage of the sunlight that falls upon their surfaces. They are tied for last place as reflectors among the major objects of the solar system in giving back only 7 per cent of the sunlight they receive.

The small mass of Mercury, combined with the tremendous temperature upon its sunward side—a temperature that ranges from about 650° Fahrenheit at aphelion to 770° Fahrenheit at perihelion—prohibits any atmosphere upon the planet. The eternally dark side of Mercury is almost as cold as anything can possibly be—very near to absolute zero,  $-459^{\circ}$ . This little tortured planet is at once the hottest and the coldest planet in the solar system as there seems to be no transfer of heat whatever through its body from the hot side to the cold side. The absence of atmosphere on Mercury is confirmed by the clear, sharp outline of the silhouette of Mercury seen against the bright face of the Sun during transits. Any atmosphere on Mercury would serve to blur and soften the edge of its disk. An analysis of the sunlight reflected from the surface of Mercury does not show any trace of gas or water vapor.

According to the laws of gravitation, the line of greatest length across Mercury's elliptical orbit, called the line of apsides, should revolve slowly about the Sun at the rate of 532 seconds of arc every hundred years. As careful observation of Mercury's position became possible, Mercury was found to be doing much better than that, and was swinging the long dimension of its orbit around the Sun at the rate of 574 seconds of arc each century. This exuberance on the part

of Mercury led astronomers to seek some outside influence that might account gravitationally for this misplacement. The influence of a planet moving about the Sun in an orbit nearer to the Sun than Mercury's orbit would have this effect, and astronomers were so sure of the existence of this undiscovered planet that they had a name all ready for it when it should finally come to light. This name was Vulcan. Every total eclipse that cast the area of space near the Sun into darkness sufficient to reveal the presence of such a planet brought about a search for Vulcan in the immediate vicinity of the Sun, but it was never found. Mercury seemed to be running wild under its own power. Finally Albert Einstein, as part of his general theory of relativity, declared that Newtonian gravity might be transgressed at extreme velocities. Mercury is going fast enough to break the law, and its excess advance in the line of its apsides is accomplished without the aid or influence of any outside planet.

Certainly any project for the personal exploration of planets other than the Earth should omit Mercury. The dreadful temperatures there, the absence of any palliating factors of atmosphere or water, and the danger of a plunge into or close to the Sun, which would result from the slightest error in navigation or the application of power, should keep it forever on the prohibited list.

## Venus

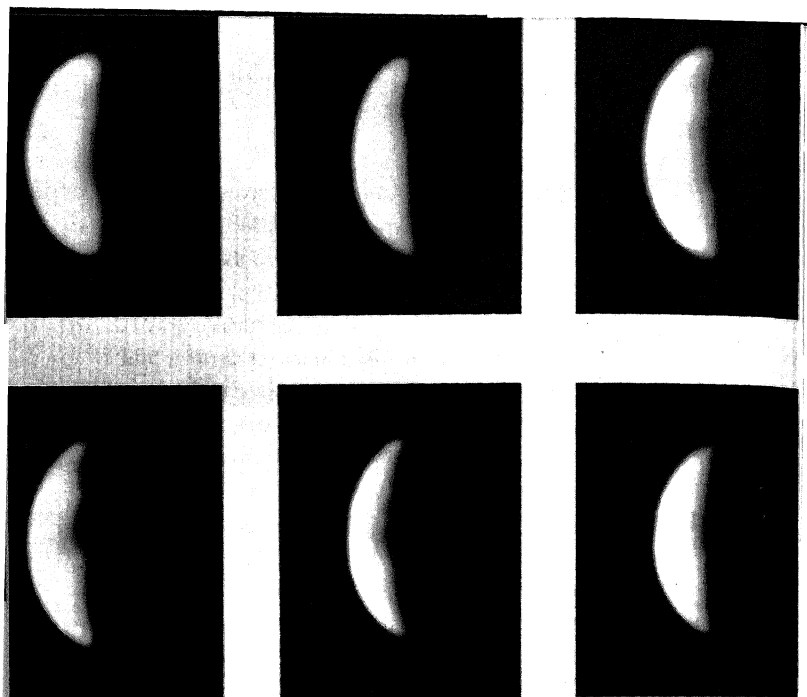
THE PROPENSITY of the planet Venus for being mistaken for something else has become a tradition. Legend, both ancient and modern, is filled with instances in which Venus, seen near the horizon by the lookout of a ship at sea, has sent that ship off course, speeding toward what was immediately accepted as a sister ship on fire. Venus, setting over the crest of a mountain, has given forest rangers on the lookout for fires, some bad moments. Aviators in war times have opened fire on Venus more often than any of them would care to admit, and Venus ranks high among the objects identified as "un-identifiable flying objects." When it is favorably situated, Venus is the third brightest of celestial objects, outranked only by the Sun and the Moon. Venus is, it must be admitted, a poor third, but it is third nevertheless.

Among all the planets, Venus has dimensions that most closely resemble those of the Earth. The size difference between Venus and the Earth may be only a few hundred miles at best, with a slight advantage going to the Earth. The diameter of the Earth is 7,927 miles at the equator. The corresponding diameter of Venus is 7,610 miles. The volume of Venus—the amount of space it occupies—is 88 per cent of the volume of the Earth, and the density of Venus, compared to the density of water, is 4.86, against 5.52 for the Earth. If the mass of the Earth be taken as unity, the mass of Venus is

0.81. Because there is a close relationship between the ratio of mass to diameter and surface gravity, the surface gravity of Venus should be about the same, in relation to the Earth, as the resemblance between the masses of the two planets. The surface gravity of Venus is 88 per cent of the surface gravity of the Earth. A man who weighs 200 pounds on Earth would weigh 176 pounds on Venus.

The brilliance of Venus is caused by the very factor that prevents our knowing more than we do about this nearest of all planets to the Earth. The amount of sunlight reflected by Venus is, according to the latest estimates, 76 per cent of the total sunlight that strikes its surface. This is almost twice as much as the Earth is calculated to reflect, in spite of the large part of the Earth's surface that is covered by that excellent reflector, water. The substance that gives back so much of the light that strikes Venus is cloud. Venus is covered with a dense, white cloak of clouds that man has never been able to penetrate. There are, on this cloud-covered disk, no permanent markings that give us any indication of the rotational speed of Venus, its inclination to the plane of its orbit, or the nature of its surface.

The first attempt to determine the length of the day on Venus—the period of time required for Venus to complete a rotation on its axis—was made by Giovanni Domenico Cassini in 1666, less than 60 years after the telescope came into use. From evidence of what he thought to be, and hoped were, surface features dimly seen on the planet, Cassini gave Venus a rotational period of 23 hours 15 minutes. Cassini succeeded rather better in assigning rotational periods to both Jupiter and Mars, but since his time, astronomy has been flooded with other estimates of the length of the day of Venus which range from within a few minutes of Cassini's figure to 225 days, which is the revolutionary period of Venus. During the last fifty years it has generally been considered that Venus turns



**Six photographs of Venus showing lack of any definite surface markings.**

slowly on its axis in about thirty Earth days, but the latest calculations, made by A. Dolfuss, a sound French astronomer, favor the longer period. This is the first of several factors that are not yet completely determined about Venus, in spite of its occasional proximity to the Earth.

Most of the authorities who produced estimates of the rotational period of Venus also gave their ideas of the angle at which the axis of rotation of Venus was inclined to the plane of its orbit. This figure fell somewhere between nothing whatever, which would have Venus standing straight up as it went about the Sun, to 75 degrees, which is a figure larger than that possessed by most of the planets. The latest estimate is that of Dr. Gerard Kuiper who in 1956 saw markings on the gleaming surface of Venus whose permanence led him to

believe that they were surface features and not transient dark areas in the clouds. From the positions and the angles of these markings as they appeared to be carried around the planet, Kuiper determined that the inclination of Venus is about 30 degrees to the plane of its orbit. If this is correct, Venus has seasons as it moves about the Sun.

These possible seasons would be slightly different from those on Earth, which are caused by the inclination of the Earth's axis to the plane of its orbit. This inclination is  $23\frac{1}{2}$  degrees, somewhat less than the supposed inclination of the axis of Venus. There would be four seasons on Venus, but they would be about equal in length because of the small eccentricity of the orbit of Venus. Each season would be about fifty-five Earth days long. For about two thirds of one season the northern, or upper, hemisphere of Venus would experience an increase of temperature similar to the coming of summer after spring upon the Earth. This would be followed by a season corresponding to our autumn, during which the Sun would appear to cross the equator of Venus from above to below. Then would come the northern winter on Venus, to be followed by spring.

The opposing hemispheres would have opposite seasons, as do the northern and southern hemispheres of the Earth. The slight difference between the length and intensity of the Earth's seasons, which is caused by the eccentricity of the Earth's orbit, would be missing on Venus. The closer approach of the Earth to the Sun in January makes the southern summer warmer and tempers the northern winter slightly, while the corresponding recession of the Earth from the Sun in July gives the southern hemisphere a more severe winter and modifies the northern summer slightly. The difference between seasonal temperatures upon Venus has not been determined, but the difference between day and night temperatures has been. The temperature of a subsolar point on

Venus has been estimated as high as  $500^{\circ}$  Fahrenheit. This is on the equator of Venus at noon. This daytime temperature is moderated near the poles of Venus and is considerably less near the morning and evening edges of the planet's disk. The dark side of Venus shows a low of about  $-10^{\circ}$ . If Venus does rotate in 225 days, it must then keep the same face turned toward the Sun, exactly as does Mercury. There are two factors in the case of Venus that alter conditions there from the severity found on Mercury. First, Venus is almost twice as far from the Sun as is Mercury. The mean distance of Venus from the Sun is 67,275,000 miles. The second factor is the presence of atmosphere on Venus. Mercury, without an atmosphere, has nothing to mitigate or lessen the extremes of sunlight or the utter absence of it that cause one of its sides to have a temperature that can be as high as  $770^{\circ}$  and the other to have one as low as  $-450^{\circ}$ . In the case of Venus there must be currents of atmosphere moving about the planet, transferring warmth or cold, as the case may be, from one side to the other, lowering the temperature on the day side and warming the night side to some extent.

The orbit of Venus lies between the orbits of Mercury and the Earth, almost exactly at the halfway point between them. Venus' orbit has the smallest eccentricity of that of any of the planets, so that it travels a path that is more nearly circular than that of any of the others. This eccentricity, which is represented by the figure 0.007, indicates that there is a difference of less than half a million miles between the distance from the Sun of the aphelion and perihelion points of Venus' orbit. Compare this with the more than 12,000,000-mile difference in the orbit of Mercury and the about 3,000,000-mile difference in the orbit of the Earth.

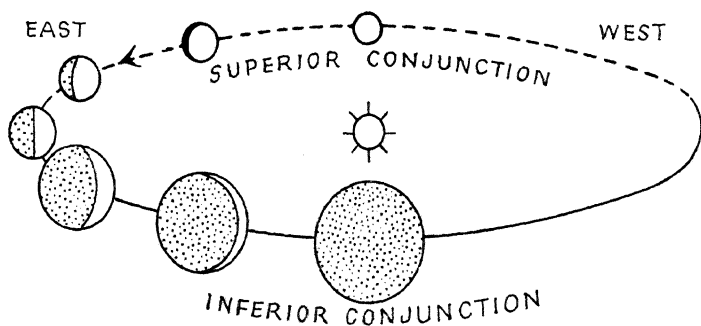
Venus moves along its orbit at a mean velocity of 22 miles a second, completing a circuit of the Sun in 224 days 16 hours 49 minutes. This is the sidereal period of Venus—the length



of time required for the planet to make one revolution about the Sun and return to the same location in space with reference to the stars. When the position of Venus with reference to the Sun and the Earth is concerned, a much longer time is required for Venus to complete a cycle of change from a given position and back to it. The combination of the rapid revolution of Venus and the relatively slower pace of the Earth makes Venus appear to overtake and pass the Earth at intervals of 584 days. This is the synodical revolution, and it brings Venus back again to the same place in Earth skies every eighteen months.

If we follow a succession of the various aspects of Venus through one synodical revolution, we find that these aspects follow each other rather slowly when Venus is near superior conjunction—when it is on the opposite side of the Sun from the Earth—while they change much more rapidly near the time of inferior conjunction—when Venus and the Earth are both on the same side of the Sun. In fact, from inferior conjunction to the next elongation—when Venus is as far to the side of the Sun as it can go, as seen from the Earth—only 71 days pass. The interval between superior conjunction and the following elongation, however, is 221 days.

These inequalities of distance are the result of the relationship of the orbits of Venus and the Earth and cause a large apparent change in the diameter of Venus. At the nearest approach of Venus to the Earth, when Venus is near inferior conjunction, the disk of Venus measures 66 seconds of arc in angular diameter. This same dimension shrinks to less than 10 seconds of arc near superior conjunction. The difference in distance between Venus and the Earth at these two positions is considerable. At superior conjunction Venus is about 160,000,000 miles from the Earth, while at inferior conjunction it is about 26,000,000 miles away, nearer than any other permanent body in space except the Moon.



**The difference between the Earth and Venus at full phase and at crescent phase causes variation in apparent size.**

The plane of the orbit of Venus is inclined from the ecliptic by a bit less than  $3\frac{1}{2}$  degrees. If the orbits of Venus and the Earth did coincide, we should see Venus silhouetted against the Sun each time the planet went through inferior conjunction. As things are, we can see such transits of Venus only when the nodes of the orbit of Venus are in the immediate neighborhood of an inferior conjunction. This does happen, but not very often. There is a sequence of transits of Venus, which gives successive intervals between transits of 8 years,  $121\frac{1}{2}$  years, 8 years, and 105 years, when the cycle starts all over again. Because of the position of the line of nodes of the orbit of Venus, transits can occur either early in June or early in December of the year in which they fall. The two most recent transits of Venus were on December 8, 1874, and December 6, 1882. The next pair of transits will be on June 7, 2004, and June 5, 2012.

Transits of Venus are of tremendous value to astronomy for they give astronomers an excellent opportunity to refine the measurement of the distance between the Earth and the Sun. In order to correct the measurements of this important distance, simultaneous observations of a transit of Venus are taken from widely separated points on the Earth's surface.



### Transits of Venus of 1874 and 1882.

Because of the angle separating the two observation points, Venus will appear to be silhouetted against different parts of the Sun's disk at each of the two locations. Triangulation of the different locations and of the angles between the points of observation will give an accurate measurement of the Sun's distance. Each successive pair of transits sees more accuracy in measuring these angles and produces a greater refinement of this figure, which is the basis for many larger measurements.

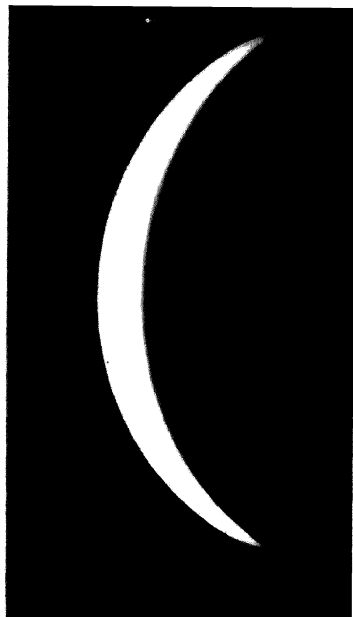
Transits of Venus are also tremendously helpful in a study of the nature of the atmosphere of Venus. When Venus is between the Earth and the Sun, the diffusion of sunlight by the atmosphere of the planet makes that atmosphere visible as a faintly luminous ring completely surrounding Venus. This delicate and beautiful spectacle is formed in the same way as terrestrial twilight. The ring is not always of the same intensity or extent. In order for the twilight ring of Venus to extend

completely around the dark disk of the planet, Venus must be at a small angle from the Sun at inferior conjunction, when the transits occur. In other words, Venus must seem to pass directly across the center of the disk of the Sun. As this critical angle increases, the extent of the ring decreases so that it sometimes shrinks to a constantly narrowing prolongation of the cusps—the pointed ends—of the crescent phase of Venus.

Venus is at its most brilliant when it is about thirty-six days either before or after inferior conjunction. This is almost a month away from the time of its greatest elongation, when it is at the widest possible angle from the Sun. It might be supposed that Venus would appear brightest when it stood at either greatest eastern or greatest western elongation, but it must be remembered that Venus is not at its closest to the Earth at its elongations. At about a month from its elongations, when Venus is either approaching or leaving inferior conjunction, it is brightest because perspective increases greatly the diameter of the crescent phase the planet shows at such times. When it is at its brightest, the crescent of Venus has a diameter of about 40 seconds of arc, but it is very shallow, only 10 seconds of arc across at its widest measurement. In spite of this small dimension, the total lighted surface presented to the Earth at such times is of greater brilliance than the greater area of the stouter but shorter crescent visible at elongations.

At times of its greatest brilliance Venus reaches a magnitude of  $-4.4$ , fifteen times brighter than Sirius, visually the brightest star. It is at such moments that Venus attains the position of being third brightest of all celestial objects, exceeded only by the Sun and the Moon. At these times, if the position of Venus is known, it can be seen in the noon sky. It is not bright enough to strike the eye and thus call attention to itself, but it is there and it is visible if it is pointed out. It

**Venus at time of greatest brilliancy  
seen from Earth.**



has also been said to cast a shadow at night during its brightest phase.

This extreme brilliance, or albedo, combined with the twilight ring seen at transits, is evidence of the extensive atmosphere of Venus. Gerard Kuiper gives the value of the albedo—the percentage of the total sunlight striking the surface of Venus which is reflected to the Earth—as 76 per cent. This is almost 20 per cent more than the estimate of previous authorities, but it has been generally accepted. At any rate, Venus is the best reflector of sunlight in the solar system, and this quality is made possible by a dense white atmosphere. The atmosphere of Venus has been studied by passing the light reflected from it through a spectroscope. Light that has made the journey through the atmosphere of Venus will bear some traces of its voyage in dark absorption lines created by cool atoms in that atmosphere. There is one difficulty: the same light will also bear traces of cool atoms in the Earth's atmosphere, through which it must also pass to get to the spectroscope. These telluric lines—lines caused by the Earth's atmos-

phere—are difficult to avoid. It is not easy to tell whether the lines of elements that we know belong to our own atmosphere are being made by that atmosphere, or whether there may not also be lines of the same elements originating in the atmosphere of Venus. Spectral lines are affected by motion to the extent that they may be shifted to one side or the other of their normal position in the spectrum if either of the two objects involved—Venus or the Earth— happens to be moving fast enough at the moment. Also, if the spectral lines could be obtained from a location in which the Earth's atmosphere could be avoided, the telluric lines would not be present.

Up to 1959 all attempts to analyze the atmosphere of Venus failed to show any trace of free oxygen or water vapor there. What was most unusual was the large amount of carbon dioxide present in the atmosphere of Venus—about ten thousand times as much as is found in the Earth's atmosphere. All these circumstances, coupled with the impossibility of direct observation of the surface of Venus, left the nature of that surface a matter for pure speculation. This speculation was aided, perhaps, by the presence of dark clouds sometimes seen in the white veil that covered the planet. These dark clouds were considered to be dust blown up from the surface. There should be winds on Venus. The difference in temperature between the dark side and the lighted side of Venus is more than 200°. Gas of whatever nature will expand and rise when it is heated, and its place near the heated surface will be taken by cooler, more condensed gases rushing in from the dark side. It has been estimated that a continuous hurricane is blowing constantly across the surface of Venus, raising clouds of dust high enough to produce the dark blotches that stain the upper surface of its atmosphere.

It is well known that at times carbon dioxide has the nature and formation of a hothouse. This would account for the high temperature on Venus, for the Sun's radiation would be trapped under this blanket of carbon dioxide that makes up the

visible part of its atmosphere. It is also thought that carbon dioxide might form a physical shell whose lowest level would be some distance above the planet's surface. This opens the field of speculation to its greatest extent, for under such a loose blanket almost anything is possible. The guesses as to the nature of the surface of Venus have ranged from a shoreless ocean to a completely waterless desert, and these two pictures leave room for an intermediate theory that Venus is a sort of celestial hothouse, damp and steamy and covered with a rank and luxurious growth of vegetation.

In the last part of 1959 an attempt was made to capture a spectrogram of the atmosphere of Venus by means of a telescope sent up in a balloon. This plan succeeded in obtaining photographs of the spectrum of Venus from a height of about 80,000 feet above the Earth's surface and, consequently, above almost 90 per cent of the Earth's atmosphere. The report of this attempt declared that definite traces of water vapor and free oxygen were found in the atmosphere of Venus. It is perhaps unwise to accept such a report as final. There was still a small percentage of the Earth's atmosphere between the subject and the camera, but if this analysis is correct, it surely opens new avenues of speculation. The presence of dust clouds—if dust clouds they are—combined with these new findings—if they are definitive—gives a picture of a world that may have both dry and wet areas and a much higher temperature on the side turned perpetually toward the Sun—if Venus is actually so fixed—and creates the possibility of another planet on which life may be found—life in the form of vegetation, at least. One of the priceless experiences that man has to anticipate is the descent through the dense clouds about Venus to find a rank, steaming jungle surrounding arid, sandy areas whipped by neverending hurricane; a wildly tossing sea with great beaches where nothing grows; a waste of wind-carved rocks much like the Painted Desert.

## Mars

FOR ABOUT TWENTY-THREE MONTHS out of every twenty-four, the most mysterious and fascinating planet in the solar system is visible somewhere in the night sky from somewhere on the Earth. This planet is Mars, bearing the name of the Roman deity after whom not only a month of the year but also a day of the week have been called. March, of course, is the month of Mars and Tuesday is the day of Mars. The name of the day has come to us from Anglo-Saxon, in which *Tiw* was the counterpart of Mars. The linguistic connection between "Mars's day" and Tuesday may be seen in the French word for Tuesday, which is *mardi*.

Mars at times exceeds in brightness those stars before which it is located. Of all the planets in the solar system, it possesses characteristics of atmosphere and surface that most resemble those of the Earth. This could be a misleading statement, but it should be remembered that the atmospheres and surface features of the other planets—what we know of them—are not in the slightest degree like the atmosphere and surface features of the Earth.

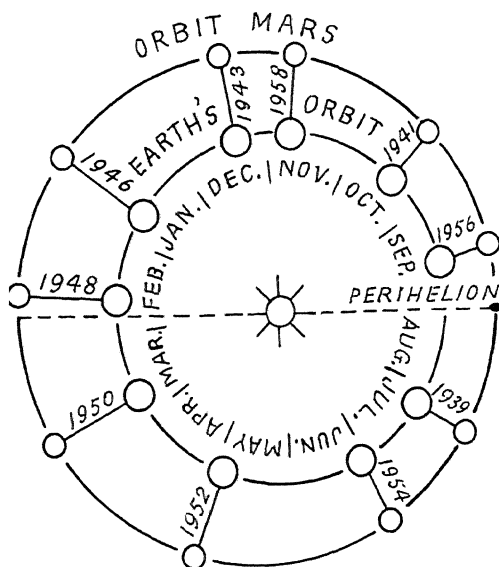
The orbit of Mars is next in order of distance from the Sun beyond the orbit of the Earth. The mean distance from the Sun at which Mars travels is 141,690,000 miles, a little more than one and a half times the mean distance of the Earth from the Sun. The orbit of Mars is considerably more elliptical



than that of the Earth, and its eccentricity is expressed by the ratio 0.093, while the eccentricity of the Earth's orbit is 0.017. Because of this, Mars is at times 26,000,000 miles nearer the Sun than at other times. The variation in distance between the Earth and the Sun caused by the eccentricity of the Earth's orbit is only 3,000,000 miles.

When Mars and the Earth are both on the same side of the Sun, with Mars, of course, beyond the Earth, the two planets are nearest to each other. This position of the two planets is called opposition because then Mars is in the opposite part of the Earth sky from the Sun, rising as the Sun sets and setting as the Sun rises. Oppositions of Mars provide the best opportunities for observation, but not all oppositions are equally favorable.

Mars moves about the Sun at a mean velocity of  $15\frac{1}{2}$  miles a second and takes 687 Earth days to complete one revolution. Because the Earth is also moving at  $18\frac{1}{2}$  miles a second, taking  $365\frac{1}{4}$  days for one revolution, 780 days must elapse between successive oppositions of Mars or, indeed, between any two successive returns of Mars to the same situation relative to the Earth and the Sun. This interval of 780 days is the synodic period of Mars. When Mars reaches that point in its orbit where it is nearest the Sun—its perihelion—it is also nearest the orbit of the Earth. If the Earth should chance to be in that part of its own orbit directly inside of the perihelion point of Mars at a time when Mars is at that point, observers will have the best possible opportunity to see Mars; but although the Earth arrives at this possible meeting place every August, Mars is not always there. When the two planets are both near these critical points in their orbits, all astronomy is alerted, and the surface of the Earth bristles with telescopes trained on Mars. The last time this happened was in 1956, and there was an opposition slightly less favorable in 1954. The next good meeting will be in August 1971, and this encounter will be the best since that of August 22, 1924.



**Relationship between orbits of Earth and Mars  
to show varying quality of oppositions.**

These circumstances account for the reason that such information as we have about the details of Mars and the general makeup of the planet have come to us not in a fairly steady stream, but in spurts at intervals of fifteen or seventeen years.

The mileage between Mars and the Earth at such times is not difficult to calculate. When Mars is nearest the Sun, its distance from it is 128,690,000 miles. When the Earth is farthest from the Sun, its distance from it is 94,250,000 miles. If we take the Earth's greatest distance from Mars's least distance, the difference is 34,440,000 miles. For the two planets to come as close together as this, however, would require perfection—with the Earth reaching aphelion as Mars reached perihelion—and this is impossible. The Earth's aphelion passage takes place early in July, while the perihelion passage of Mars does not occur until August. At best, the approach of the two planets to each other cannot be closer than 34,500,000 miles. This is considerable distance, although it may be in-

significant astronomically. It puts Mars, at best, 150 times as far from the Earth as the Moon is. If we can see objects on the Moon that are a quarter of a mile in diameter, an object on Mars, to be seen with the same relative distinctness, cannot be less than 38 miles in diameter.

What are we looking at, from this minimum distance of 34,500,000 miles? We are looking at a planet whose diameter is a bit more than half the diameter of the Earth. Mars measures 4,221 miles through its equator, with a possible error of no more than 10 miles. Mars is slightly oblate—flattened at its poles—in the proportion of 1 part in 190. Its surface area is 29.1 per cent of the surface area of the Earth and its volume is 15.3 per cent of that of the Earth. Mars is not as compactly constructed as the Earth. Its mass is about 11 per cent of the mass of the Earth, which means that its density is about 70 per cent of the Earth's density, or 4.12 times the density of water.

The surface gravity of Mars, which is dictated by a combination of the planet's mass and its radius, is 37 per cent as powerful as that of the Earth. If an object that weighed 100 pounds on the Earth were taken to Mars and placed on a spring scale, it would weigh 37 pounds. The velocity of escape from Mars is consequently less than the velocity of escape from the Earth. To free ourselves from the authority of the Earth's surface gravity, we must surpass a velocity of 6.7 miles a second. We could get away from Mars by revving up to  $3\frac{1}{4}$  miles a second. The velocity of many of the molecules of ordinary gases often exceeds  $3\frac{1}{4}$  miles a second, especially in warmer temperatures. Although temperatures on the surface of Mars are anything but balmy, it does get sufficiently warm during daytime there to speed up many molecules to velocities in excess of the velocity of escape. It is possible that for millions of years whatever atmosphere Mars may have had has been slowly leaking out into space during the warmer days on the planet. It is obvious that there is an

atmosphere of sorts on Mars. Spectroscopes fail to show any free oxygen or water vapor in the Martian atmosphere, but this is more likely the fault of the spectroscope, which cannot detect quantities as small as may be there. The oxygen and water in the Earth's atmosphere produce lines in the spectrum of any object in space. If there is also water vapor or oxygen on Mars, such lines as they cause would coincide with the telluric lines—those made by Earth's atmosphere—and would be impossible to isolate. A barometric pressure of about one tenth the barometric pressure at the surface of the Earth is estimated for the Martian atmosphere.

Other evidence points quite definitely to the presence, perhaps to a greater extent in the past than now, of oxygen in the atmosphere of Mars. The red color of Mars would indicate that the soils of Mars may have absorbed oxygen from the Martian atmosphere. This redness may be the result of oxidization, or rusting. Clouds have been seen close above the surface of Mars, and white mists often blur and obscure the polar regions. Indeed, during the opposition of 1956 a strange cloud formation was witnessed on Mars every day for several days. At about the same time every Martian day, a cloud shaped like an enormous W appeared over the same part of the Martian surface. The reason for this regular reappearance was not known, but it was probably due to some combination of temperature and irregularity of the Martian surface. If that W were turned upside down, it would have made an acceptable M, the initial for Mars, but apparently no attempt was made to read into this freakish formation an effort on the part of any intelligence on Mars to label the planet. Yellow clouds—perhaps fine dust lifted from the surface of Mars by the light breezes, which are all the winds possible there—have been reported from time to time. There is also a blue haze, almost violet in tone, which frequently appears surrounding the entire planet. This may be the reflection of sunlight from and through ice crystals, for it is well

agreed that the polar caps are frozen water. It would hardly be proper to call them ice, for the deposit must be very light—more like a heavy frost—but it is upon these polar caps and the violet haze and certain other manifestations, which will be detailed later, that the presence of water is postulated there.

Mars rotates upon its axis in almost the same period of time as does the Earth. A day on Mars is 24 hours 37 minutes 22.58 seconds long. This means that we can see very nearly the same part of the planet's surface each night for many nights in succession. Because of the slight difference between the rotational periods of Mars and the Earth, the markings we see on Mars appear to move backward—against the direction of rotation on Mars—as we watch, being displaced by about 9 degrees, or about one twentieth, of the visible disk of Mars each night. After forty nights of watching, the same part of Mars that we saw on the first night of our vigil would be back in position again. If a team of observers were so placed that some of its members could observe Mars all through twenty-four hours of darkness, the sum of all its observations would cover almost all of the surface of Mars. During the night some of them would see Mars as much brighter than it appeared to others, for there are markings on Mars that make a difference of about 15 per cent between the albedo of different areas on its surface. The total albedo of Mars—the astronomical measure of its ability to reflect sunlight from its surface—is 14.8 per cent. That is a little more than twice the albedo of either the Moon or Mercury but only about one fifth of the albedo of Venus. This makes Mars about as efficient a reflector as dark rock, and the chances are that dark rock is what most of the visible surface of Mars is made of.

Mars is tipped away from the vertical as it goes around the Sun, very much as the Earth is and to almost the same degree. The inclination of the polar axis of Mars away from the plane of its orbit is 25 degrees 58 minutes, as compared with the Earth's inclination of 23 degrees 26 minutes 45 seconds. This

means that Mars has seasons. It is interesting to compare the lengths of the seasons on the northern hemispheres of Mars and the Earth, remembering that the year on Mars is almost twice as long as the year on Earth.

| <i>Season</i>    | <i>Earth</i> | <i>Mars</i> |
|------------------|--------------|-------------|
| Winter to Spring | 89 days      | 160 days    |
| Spring to Summer | 93 days      | 199 days    |
| Summer to Autumn | 93 days      | 182 days    |
| Autumn to Winter | 90 days      | 146 days    |

Mars also resembles the Earth in that the summers of its southern hemisphere are shorter and warmer and its winters longer and colder than those of its northern hemisphere.

The north pole of Mars is aimed constantly at the same point in space very much as is the north pole of the Earth. The coordinates of the point at which the north pole of Mars is directed are right ascension 22 hours 10 minutes, declination 54 degrees north. This makes the extension of the north pole of Mars point to a place in the sky about 2 degrees from Zeta Cephei, a third-magnitude star in the constellation of Cepheus.

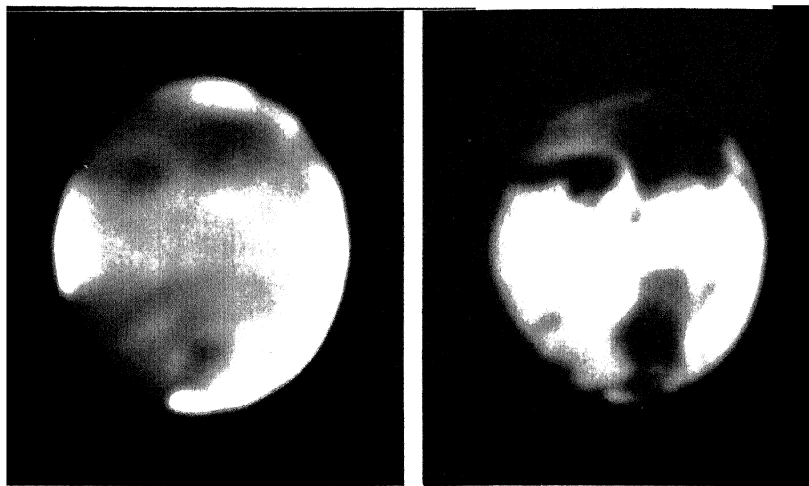
The plane of the orbit of Mars is inclined by  $1^{\circ}.8$  from the ecliptic—the plane of the Earth's orbit. The various positions and motions of Mars combine to place it in a situation most favorable for observation from the Earth when its southern hemisphere is slightly inclined toward the Earth and we are able to see its south pole. At times of favorable oppositions, the southern hemisphere of Mars is approaching midsummer.

The first observer of Mars by telescope, Galileo and his contemporaries, saw that Mars did not constantly show all its lighted side to the Earth, but was in a gibbous phase, shaped somewhat like the Moon when it is two or three days from full. Little else was seen on Mars for about ninety years after the discovery of the telescope, but in the middle of the seventeenth century, Christian Huygens, who made the first efficient eyepieces for telescopes, reported seeing polar caps of

dazzling whiteness on Mars. These have been seen since by every observer, and their behavior through the Martian seasons has been carefully charted. At the winter solstice of Mars, the white polar cap often extends halfway from the winter pole of Mars to its equator. This is the same situation in which we find the Earth when winter snows sometimes whiten its surface considerably more than halfway from the pole to the equator. A short time before the spring equinox on Mars, the winter cap begins to shrink steadily until, by the time of the summer solstice, it has been reduced to a diameter of 500 or 600 miles, and later in the summer it is considerably smaller.

Shortly before the autumnal equinox the polar cap of Mars begins to form again, usually in small patches separated from each other near the pole. These patches merge and grow together from that time on until the winter cap is complete, to remain so until the following spring. There is considerable difference between the formation and behavior of the northern and southern caps. At times the southern cap will disappear completely during summer on the southern hemisphere of Mars, while the northern cap has never been known to vanish entirely. In the southern winter, however, the cap around the south pole of Mars grows to a much larger area than does the northern cap in the northern winter. The southern cap, in spite of its ultimately greater extent, begins to form later in the season than the northern cap and starts its spring disintegration earlier. This behavior of the caps is in accordance with the variations in intensity and temperatures of the southern winter on Mars.

As the polar caps shrink with the coming of spring, isolated patches of white are left, always in the same places each season. These patches remain visible for a much longer time than the cap as a whole. In the southern hemisphere the last patch of white to go—and it sometimes stays all through the Martian summer—is about 250 miles from the south pole of



**Mars in blue light (left) showing white clouds over polar caps and general atmospheric haze. Photograph in red light (right) shows small polar cap at lower pole and stable green areas which appear dark in photograph.**

Mars. This tenacity probably indicates that the surface upon which these patches lie is elevated above the general level of Mars and is cooler because of its greater height. It is highly improbable that the surface of Mars is a single, great uniform plain, but there are no abrupt elevations or depressions visible there. It has been estimated that any sudden elevation of more than 2,500 feet could easily be seen, but none has been discovered. It has been judged that the variations in altitude of the Martian landscape are small and that the surface generally must be one of low, rolling hills. Even so, if the rises are sufficiently gradual and constant, it is possible for some parts of the Martian surface to be thousands of feet higher than others.

Apart from the gleaming white of the polar caps, the predominating color of the Martian surface is either reddish brown or a varying green. When the green regions were first seen and when sufficient observation of them had established that they were permanent, not changing in size or shape to any extent, it was assumed that they might be large bodies of



water. Giovanni Virginio Schiaparelli, one of the most famous observers of Mars, named them accordingly on his charts of Mars, and his marine designations have been adopted and generally retained, although it is now believed that these are not large water areas. If the green regions were covered with water, there would certainly be some occasional isolated brilliance at those times when the rays from the Sun were reflected from the surface of water at the correct angle to strike the eye of the observer. Further, certain stable, unchanging details have been seen in many places within the green areas. If these regions were large bodies of water, it would be most unlikely that fixed details could be constantly observed on them, no matter how clear or shallow their waters might be.

The color of these green areas and even their dimensions vary with the Martian seasons. In the Martian winter they become appreciably smaller, and their color then is generally a rather pale brownish green, sometimes difficult to distinguish against the background of reddish soil. As spring comes to Mars, this color deepens to a light and delicate but definite green. During the summer these areas grow darker, and some astronomers have described them as being a blue-green. Toward the end of the summer they change again and become brown and yellow, and their size decreases somewhat. In many cases yellow and brown islands will appear temporarily within green areas.

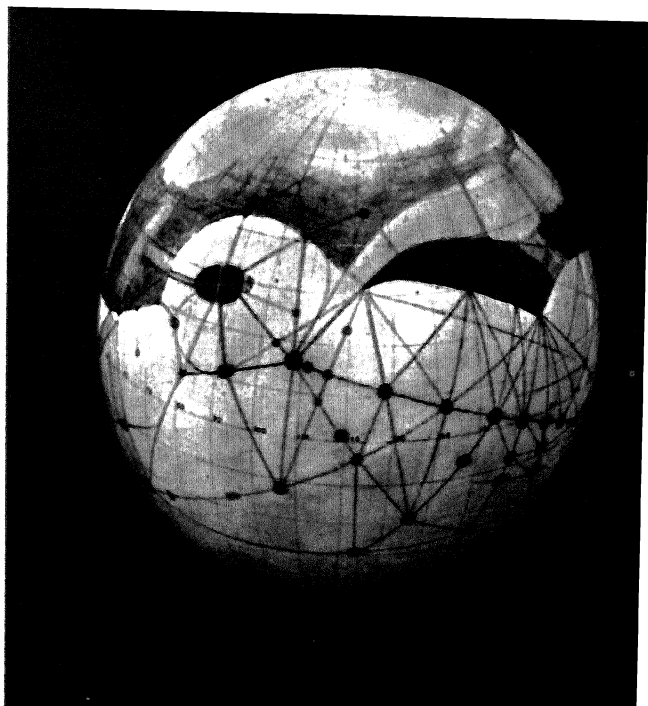
This color change is one with which inhabitants of the northern hemisphere of the Earth should be familiar, for the vegetation of this part of the Earth goes through a similar color cycle. The color changes on Mars, particularly those that take place in the Martian spring, coincide with the shrinking of the Martian polar cap, and the first tinge of green seems to progress from the Martian pole toward the equator. This has been called "the wave of quickening," of life returning, through the medium of moisture, to the green

regions. This metamorphosis has given rise to the theory, accepted by many astronomers, that the green areas of Mars are made green by a thin cover of vegetation. This vegetation cannot be grass or forests but may be rather an extremely hardy type of moss or lichen, such as might be found in the polar regions of the Earth. This could exist with a minimum of water and oxygen and under extremes of temperature.

Other astronomers have advanced alternate theories to account for the coloring of Mars. One prominent astronomer has suggested that the dark areas are impregnated with soluble salts that look dark when they are moist but that dry to a pale brown. Similar conditions may be found in the alkali flats of our western deserts. A more recent theory attributes the greenish appearance of these large areas to an optical illusion in which gray surfaces adjacent to orange-red surfaces will look green by contrast, particularly when they are dimly seen. Green and red are complementary colors, and experiment has shown that when surfaces of gray and red are side by side, the gray will appear green as long as the red surface is also seen. When the red surface is covered, however, the gray reverts to its true color.

The temperatures of Mars are, to say the least, severe by Earth standards. At what might be the warmest spot on Mars—the subsolar point on the Martian equator during equinoxes at noon—the temperature may rise to almost 70° Fahrenheit. At that same place and on the same day at sunset, however, the mercury could fall to a bitter 90 degrees below zero. The tenuous Martian atmosphere is not capable of retaining the radiation from the Sun. The rare and thin clouds, mainly dust, that have been seen from time to time above the surface of Mars are not sufficiently long-lived to blanket that surface and retain solar heat.

At times, during the last hundred years, observers have drawn on sketch maps of Mars made from visual observation, narrow lines, usually shown as crossing the red areas. In 1877



**Antoniadi's map of Mars.**

these vague hints came to a sudden and rather startling climax. During the summer of that year, in August, there was an exceptionally favorable opposition of Mars. That planet and the Earth approached the critical points in their orbits within a short time of each other, and many astronomers devoted their nights during that summer to peering at Mars in the hope of learning more about the mysterious markings on its surface.

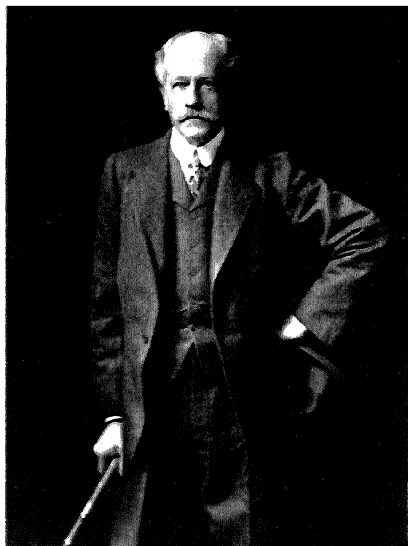
In Italy Giovanni Virginio Schiaparelli had everything in his favor. A series of nights of superior clarity provided excellent seeing, and he had a fine telescope by Merz, one of the great German telescope makers. Schiaparelli watched assiduously for weeks and, at the end of his vigil, wrote a voluminous and detailed report. In it, he declared that he would describe the various markings that he had been able to see on Mars in

terms of similar features of the terrestrial landscape, such as capes, promontories, islands, channels, and the like. Among many other things, Schiaparelli saw and described many fine lines crisscrossing much of the reddish area of Mars and even encroaching on the green regions. He called these lines channels and for "channels" he used the Italian word *canali*. *Canali* looks very much like the English word "canal." There is, however, a great difference in implication between "channel" and "canal." A channel can be worn in loose soil by a casual and undirected flow of water. A canal, however, implies construction, engineering, and intelligent planning. Nowhere did Schiaparelli come out and say that he believed what he saw to be artificial waterways, but neither did he declare that he really meant channels instead of canals. His report was received: *canali* was translated as "canals," and the fat was in the fire.

Mars instantly became populated by a race of super beings, cities sprang up there, and writers by the thousand capitalized on the situation. The greatest of these writers was H. G. Wells. His superlative novel *The War of the Worlds*, based upon an invasion of the Earth by creatures from Mars, is still one of the most exciting and best-written works of science fiction. This novel was the basis for the famous radio broadcast of Hallowe'en of 1938, in which Orson Welles frightened much of the population of the New York metropolitan area into the hills. H. G. Wells also wrote several short stories dealing with a possibly inhabited Mars.

It was obvious that astronomy was going to check Schiaparelli's findings carefully and thoroughly. Schiaparelli himself was above criticism as an astronomer, respected and honored, and head of the great observatory at Milan. Since his time many others have examined Mars with great care, and the canal score is about even. Perhaps half of the professionals who have had good opportunities to observe Mars since 1877 have seen canals; half have not. The descriptions

**Percival Lowell**  
(1855-1916)



of the individual appearances of the canals vary widely, but, oddly enough, the locations and the general courses of the canals as mapped by those who have been able to see them are remarkably in agreement. Everyone who has seen them has seen them in the same places on Mars. Some have seen them as fine lines; others have seen thick lines, blurred at the edges; some have seen the lines doubling at the height of the Martian spring season; many have seen dark spots of considerable area at the junction of two or more of the canals.

The saga of the Martian canals had a tremendous fascination for a wealthy American who had spent some years in the diplomatic service of the United States in Korea. Percival Lowell, whose sister Amy was one of the great poets of America and whose brother A. Lawrence was for many years president of Harvard University, built a private observatory at Flagstaff, Arizona. He equipped this observatory with fine instruments and staffed it with first-rate technicians to study the situation on Mars. Lowell was one of those fortunate beings who had no trouble in seeing the canals. His observations cover many years, and his maps of Mars are as detailed and as meticulously drawn as navigational charts. He saw the

canals. He saw the dark spots at the junctions of the canals and called them oases. He watched the canals double in the spring, a process that he called gemination. He found canals crossing not only the red areas but the green regions as well. Lowell wrote two books promoting his theories about the condition of Mars: *Mars and Its Canals* and *The Evolution of Worlds*. Mars was inhabited by an intelligent race. Indeed, the Martians exceeded the inhabitants of the Earth in intelligence and in organization, for there were no breaks or boundaries in the canal system that Lowell had seen there. Hence, the entire planet of Mars must have been under one central government. Its inhabitants had succeeded in uniting in one organization whose authority embraced the entire planet.

Information gained since Lowell's time about both Mars and the nature of life itself have ruled out the possibility of organisms on Mars at the level of human life. We are now certain that life, wherever it may appear, cannot differ greatly from the forms that we know on Earth, which are, certainly, widely diversified. We know that life cannot exist outside of a fairly narrow range of temperature, oxygen, water, and radiation. The Earth's supply of these essentials covers this range with something to spare, but that of Mars does not. Beyond the possibility of primitive vegetation and bacterial life, probably nothing else can be there. We still do not know what the canals may be. Possibly they are channels caused by the flow of water from the melting polar caps; possibly they are a pattern of hit-or-miss fine markings which are translated into regular lines by the straining and wishful eye of the beholder. Photographs have not yet answered the canal question satisfactorily. There are one or two exceptional photographs on which it may be said that the canals—or one or two of the most prominent of them—can be seen. The grain of photographic emulsion is still too coarse to show a clear image of such fine lines, and during the length of time

that must elapse while a long-exposure photograph of Mars is taken, the planet will rotate sufficiently to blur any such lines. Something is there, dimly seen in the best of the pictures made through the great telescopes, but in this instance the eye itself is better than the camera.

In instruments of the best size for visual observation of Mars, the planet presents a disk about 8 millimeters in diameter—about the size of the cross-section of an ordinary lead pencil. This disk is seen boiling and bubbling in such turmoil that details are completely invisible. This boiling is the effect of the Earth's atmosphere upon the light from the remote planet which must pass through that atmosphere to reach the telescope. With patience the observer may, at widely separated and short intervals, see this disturbance grow quiet and cease as the turbulence of the atmosphere subsides. As he watches, the irregular, dancing disk of Mars becomes steady and takes on a sharp, definite edge. A white polar cap appears, and the detail of its edge can be seen, usually marked by a broad, brownish line, such as might be made by moisture soaking into loose, sandy soil. The pink color of the planet concentrates into a definite pattern, and the green regions take form. Then, if the period of good seeing lasts long enough, the fine markings may become visible. These have been described by E. E. Barnard as "painted with a grayish colored paint, applied with a very poor brush, making two long, lazy, parallel streamers and producing a streaky and wispy effect in the darker regions."

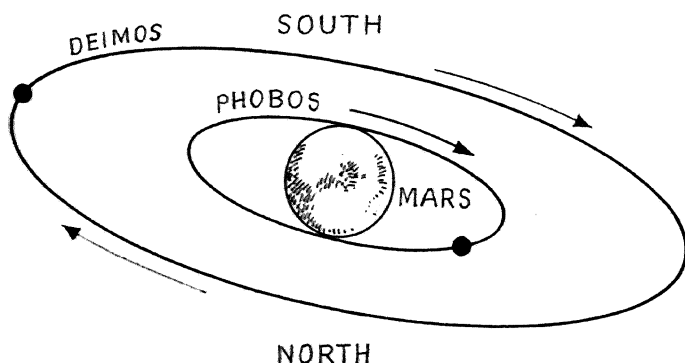
After an interval usually measured in seconds, the turbulence again takes over, the little pink disk again begins to boil, and the instant of good seeing has gone. Many such tantalizing glimpses have been used to make the picture of Mars that we know—a picture built like a mosaic, bit by bit, out of tiny fragments. Photographs must be exposed for several seconds in order that the faint light from the planet may register on even the fastest emulsion, and there have not

yet been sufficient consecutive clear seconds of time to produce a satisfactory picture of the elusive detail of Mars's surface. Perhaps by 1971, when the next favorable opposition will take place, we may have developed light intensifiers that will throw large, clear images of Mars, on screens similar to television screens, bright enough to be photographed for as long as the planet remains above the horizon. Then perhaps the secret of the canals may be discovered—if man has not gone to Mars in person in the meantime.

Mars has two satellites. They are as strange and unusual a pair as are to be found in the entire solar system. One of them, the larger of the two, revolves around Mars at a distance of 5,820 miles from the center of Mars—somewhat less than 4,000 miles above the surface of Mars. It moves from west to east, in the same direction in which Mars rotates, but its revolutionary velocity is so rapid that it completes a journey about Mars in 7 hours 39 minutes—making three such trips in the time Mars requires for one complete rotation—three circuits a day. The diameter of this inner satellite is about 10 miles, although it is difficult to measure accurately from Earth.

The second satellite, about half as large as the first, is 14,600 miles from the center of Mars, or almost 13,000 miles from its surface. It, too, moves rapidly, completing one

**The orbits of the Martian satellites.**





revolution in 30 hours 18 minutes. These satellites were discovered in that same tremendous year in Martian history, 1877, by Asaph Hall, an American astronomer working at the Naval Observatory in Washington, D.C. The legend runs that Hall had spent most of that summer searching for possible satellites of Mars and had just about given up when his wife persuaded him to make one more try. He had been searching at the distance from Mars where a normal satellite might have its orbit. He swept closer to Mars on this last night and picked up the inner satellite first. Soon afterward he found the other. Hall was given the privilege of naming these strange little objects, and he selected Phobos for the larger and Deimos for the smaller of the two. These names—the Greek words for “fear” and “terror”—come from the mythology of Mars. They are the names either of two companions of Mars or of the horses that drew the chariot of Mars.

Remember the date of this discovery, 1877. Now, turn to *Gulliver's Travels* by Jonathan Swift, published in 1726. One of Lemuel Gulliver's voyages took him to the weird land of Laputa, a country inhabited by a master race of absent-minded scholars who walked about in thought-induced trances until summoned back to reality by being struck gently by inflated bladders in the hands of their attendants. Gulliver reports that these savants “have discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the center of the primary planet exactly three of the diameters [12,300 miles], and the outermost five [20,500 miles]; the former revolves in the space of ten hours, and the latter in twenty-one and an half; so that the squares of their periodical times are very near in the same proportion with the cubes of their distance from the center of Mars, which evidently shows them to be governed by the same law of gravitation, that influences the other heavenly bodies.”

Remember that Newton was still alive in 1726, and that

Kepler had been dead less than 100 years, and 1877 was 150 years away. Remember also that Phobos is the only natural satellite in the solar system that revolves about its planet in a shorter period of time than is taken by that planet to complete one rotation on its axis. It is possible that Swift was lampooning the British Royal Society, which was regarded with some derision by the educated men of England at the time, for its endeavors to solve completely impractical problems. Newton had published his *Principia* some years before, and Swift may have tried to choose what he believed to be a ridiculous example of the principles of the law of gravitation that were outlined in that work. In any event, the example he chose turned out to exist in so close a parallel that the uncanny description of the two satellites of Mars 150 years before their discovery has been one of the great wonders of literature.

A Russian newspaper published a theory a short time ago that paints a picture of desperate terror and scientific emigration on the part of a people from a dying planet. It tells that there was at one time sufficient atmosphere and water upon Mars to support life—a view that is not uncommon. As the atmosphere and water vapor of Mars slowly leaked away into space because of the small mass and consequent low escape velocity of the planet, the population, probably dwindling rapidly in numbers, built a haven against slow extinction in the form of an artificial satellite—probably launching its various components into orbit and assembling them in the gradually diminishing atmosphere. They stocked their satellite with the necessities of life and with the means of continuing these necessities, and they may be there now, riding forever around and around their dead home in the object that we call Deimos. The subject has been treated before this in science fiction.

The future may bring a practical use for one or both of these tiny satellites. We have talked at great length here on

Earth about the construction of a space platform, a permanent space station, orbiting about the Earth at a distance of slightly more than 1,000 miles, where it could stay forever in theory, and probably in actuality. This station above the atmosphere of the Earth would provide an invaluable laboratory for scientific research, an unequaled astronomical observatory, a jumping-off place for travel farther into space, and so on. Mars has two built-in space platforms, and we are already casting covetous eyes upon them. Phobos or Deimos will certainly welcome travelers from Earth before Mars does.

## Jupiter

AT THIS POINT we must cross a tremendous gap in the captive family of the Sun. We have been visiting the small planets—and we must include the Earth among these. The small planets have many points of similarity. They are, with one exception, close to the Sun. Only Pluto ranges through the outer extremities of the system. The small planets all have comparatively long periods of rotation. Mercury rotates once in 88 days; Venus' period of rotation is somewhere between 30 and 225 days; Pluto rotates in  $61\frac{1}{2}$  days; and the Earth and Mars rotate in strangely similar periods of about 24 hours. All of these tiny bodies are lagging as they spin, by comparison with the giants.

All of the small planets are alike, too, with respect to the amounts of atmosphere they carry about with them. This should follow, since the presence of atmosphere indicates a mass sufficient to generate surface gravity. Mercury has no appreciable atmosphere. Venus has an atmosphere opaque to light, but one that is not extremely deep. The Earth's shell of atmosphere extends outward only about 1,000 miles from the Earth's surface, and 75 per cent of this atmosphere lies within 10 miles of the surface. Mars has an atmosphere so tenuous that it will support a column of mercury only  $11\frac{1}{2}$  inches tall—about one tenth as heavy as the atmosphere of the Earth—and Pluto, as far as is known, has no atmosphere.

Pluto falls into this planetary group only because of its size, and even that is not definitely known. Its probable past history as a satellite of Neptune must be taken into consideration in comparing its characteristics with those of the other small planets.

As we go outward past Mars into the solar system, we leave behind any remote possibility of life and of future goals for travel by the inhabitants of the Earth. From temperatures against which we might shield ourselves, from atmospheres whose most dangerous quality is their inadequacy, we move out into the deep freeze of space to great planets that carry death on their surfaces. To reach Jupiter, not only must we cross the belt of the asteroids, but we are also going away from the Sun. Out here, following a path that measures almost 2,400,000,000 miles in one revolution, Jupiter swings around the Sun in an orbit that brings it at one point as near to the Sun as 366,000,000 miles and takes it as far from the Sun at another point as 599,600,000 miles. The mean distance between these two extremes, the distance usually given for Jupiter from the Sun, is 483,300,000 miles.

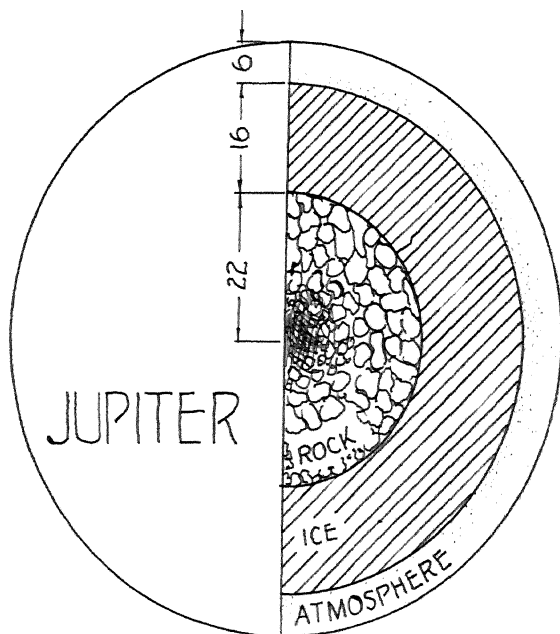
Jupiter is the largest of the planets. Its equatorial diameter is 88,640 miles, but because of its rapid rotation, much of its substance has been forced into the region of its equator, leaving its polar diameter considerably shorter than the distance through it at its equator. Jupiter measures 85,160 miles through its center from pole to pole, and its mean diameter, still most impressive for a planet, is 86,900 miles—about eleven times the diameter of the Earth. The flattening of Jupiter at its poles, its oblateness, is 1 part in 15.4, the largest of any of the planets. This distortion is accounted for chiefly by the speed of Jupiter's rotation. The planet completes one spin on its own axis in 9 hours 55 minutes. This speed moves a point upon Jupiter's equator at the rate of about 28,000 miles an hour, as against slightly more than 1,000 miles an hour for a point similarly situated on the

Earth. The difference in distance from the center of Jupiter between its poles and at its equator would make an object at a pole of Jupiter weigh 15 per cent more than at its equator. This same condition is found to a smaller extent upon the Earth, where a man weighs  $\frac{1}{189}$ th more at the poles than at the equator.

While some of this difference in dimension of Jupiter is contributed by the solid part of the planet, much of the visible diameter of Jupiter is made up of the gases of its atmosphere. There is probably a fairly small but highly concentrated central region. Jupiter, like the rest of the giant planets, is considerably less dense than any of the terrestrial planets. Jupiter is less than a quarter as dense as the Earth and is not even as dense as the Sun. The specific gravity of Jupiter is 1.3, as against 5.52 for the Earth and 1.4 for the Sun. For its size, then, Jupiter must have a deep shell of atmosphere and a small solid center. Rupert Wildt, an astronomer at Yale University, has constructed a hypothetical model of Jupiter which has a rocky core about 38,000 miles in diameter. Above this core, Wildt puts a layer of ice about 17,000 miles deep and surrounds this with an atmosphere 8,000 miles deep. Other estimates of the depth of Jupiter's atmosphere run as small as 200 miles.

There are still other pictures of Jupiter that give the planet no definite central core whatever, supposing it to be a sphere of gas with a tremendous central condensation caused by the gravitational pressure there.

At Jupiter's distance from the Sun, the average surface temperature is about 200 degrees below zero Fahrenheit. Ammonia freezes at 100 degrees below zero; yet there are indications, gained by spectroscopic analysis of the sunlight reflected from and through Jupiter's atmosphere, that ammonia is present there as a gas. It may be that Jupiter is slightly warmer beneath its cloudy atmosphere than at the upper surface of that atmosphere, or that the ammonia is



**Theoretical cross-section of Jupiter.**

subliming, or steaming off, under the touch of the distant Sun. Methane is also found in Jupiter's atmosphere, but it remains a gas until the temperature drops to 240 degrees below zero. Both methane and ammonia are combinations of hydrogen and either carbon or nitrogen, and the presence of a vast amount of hydrogen must be accepted on Jupiter. Hydrogen is the most abundant element in the universe, and the surface gravity of Jupiter is so strong that a velocity of escape of 37 miles per second is maintained there. This high velocity would hold the hydrogen upon Jupiter, and the presence there of oxygen, also an abundant element, would account for the thick sheath of ice postulated by Wildt.

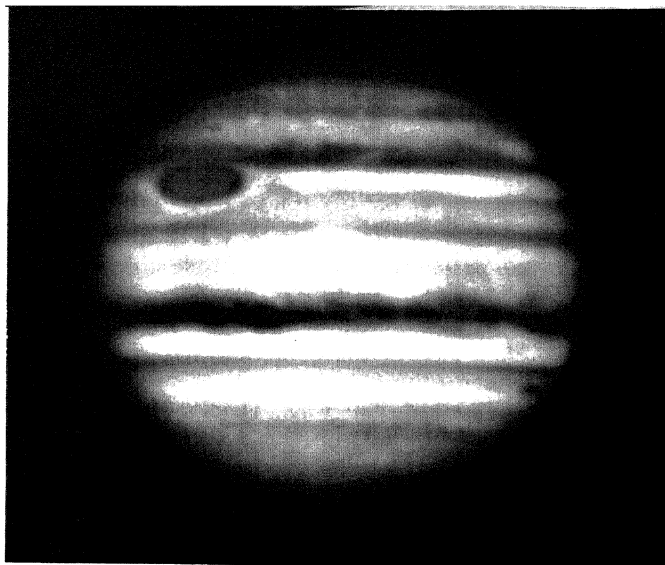
Jupiter completes its journey around the Sun in 11.86 years, traveling at about 8 miles a second along its orbit. That is, of course, the mean velocity between the more rapid progress of the planet at perihelion and its slower rate at aphelion.

Jupiter's velocity combined with the speed of the Earth brings Jupiter into the same relative position with the Earth every 399 days. Thus, Jupiter is visible in the sky for most of the year, when the nights are clear. For about two weeks each year, Jupiter is in the same direction from the Earth as the Sun and is lost in the latter's overwhelming glare. At other times, at some part of the night, Jupiter shines almost as bright as Venus. At its brightest Jupiter is more than twice as bright as Sirius, the brightest of the stars, and at its faintest, when its distance from the Earth is increased by the diameter of the Earth's orbit—almost 186,000,000 miles—it is not quite as bright as Sirius.

The size of the visible disk of Jupiter—its apparent diameter—also varies according to the perspective of distance. When Jupiter is in opposition—on the same side of the Sun as the Earth but, of course, beyond the Earth—it is nearest to the Earth and its disk measures 50 seconds of arc in diameter—one thirty-sixth of the apparent diameter of the full moon. When Jupiter is in conjunction and on the far side of the Sun from the Earth, its apparent diameter dwindles to 32 seconds of arc, or about one sixtieth of the apparent diameter of the full moon.

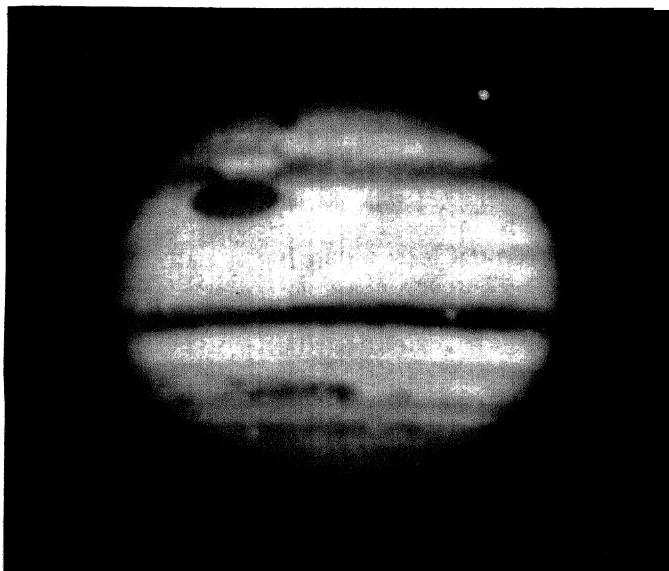
Jupiter is an entrancing sight in a small telescope. An instrument at least 3 inches in diameter is needed in order to see any markings on the planet, and a 6-inch reflector will show the oblateness of Jupiter as well. Seen thus, Jupiter presents a bright ball, slightly flattened at its poles and marked by streaks of cloud formation that cross its disk parallel to each other and its equator. There are several of these streaks, varying in intensity, with the darkest and most apparent line lying near the center of the visible disk. If powers of 200 or more can be used in a 6-inch telescope with good seeing, irregularities can be detected in the pattern of these lines. There are spots, usually oval, breaking up the evenness of the cloud streaks. The Great Red Spot is often seen:





**Jupiter showing cloud bands and Great Red Spot.**

**Jupiter showing the satellite, Ganymede, and shadow of satellite on surface of clouds.**



this is an elliptical region, about 30,000 miles long and from 7,000 to 8,000 miles from top to bottom. It extends horizontally about one third of the distance between Jupiter's equator and its south pole. It was first seen in 1831, although no particular mention was made of it until about 1878.

According to descriptions of it at that time, its color was a deep brick red, but it appears to have faded considerably since then. The origin of this and other spots, none of which has lasted anything like as long as the Great Red Spot, is still a matter of conjecture. There must be considerable turmoil in the deep and dense atmosphere of Jupiter, and it is possible that the spots are the visible evidence of what might correspond to storms. They seem to drift and to be clouds rather than permanent landscape features. There is a theory that the more prominent spots may result from volcanic eruptions from the surface of Jupiter, deep beneath the atmosphere, but this is conjecture and may not account for the instability of position of the spots as opposed to their longevity. The spots are still as much a mystery as the canals of Mars.

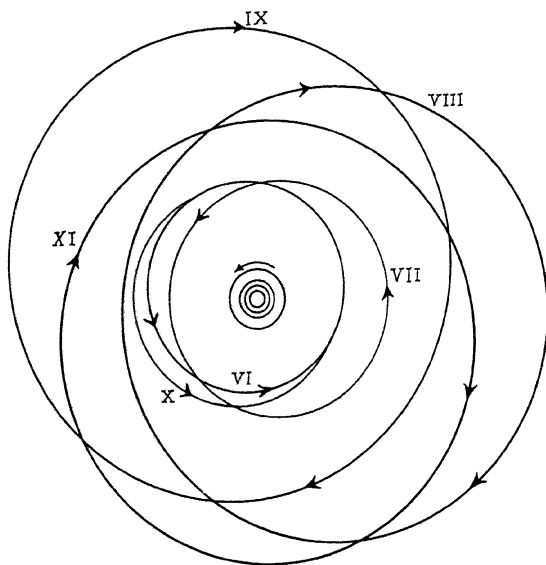
A few years ago two young astronomers working with a radio telescope heard definite sounds through the receiver of their instrument, which they were able to identify as coming from Jupiter. Exactly what forces on the planet could produce sufficient energy to travel across nearly half a billion miles and make itself heard at the end of such a journey is not yet known, but they may be the result of disturbances connected with the dense atmosphere and its friction with the surface of the planet itself or of eruptions in a possible central body within Jupiter's atmosphere.

Through an ordinary optical telescope, four of the members of Jupiter's satellite family are easily seen. Jupiter has the largest such family of any of the planets: there are twelve in its entourage. Three of the four that are so easily visible are each larger than the Earth's Moon, and two of them are

greater in diameter than Mercury. Their names, in order of their distance from Jupiter, are Io, Europa, Ganymede, and Callisto; these are also the names of four individuals who figure largely in the Jupiter legend in classical mythology. The exact measurements of these satellites are difficult to determine and are generally rounded out to reasonable figures. Their mean distances from Jupiter, too, are approximate, although their orbits are very nearly circular and there is little difference between the perijovian and apojovian positions.

The four larger satellites are bright enough to be seen under ideal conditions without telescopic aid, if Jupiter were not there to overwhelm them with its own brilliance. This is a bit difficult to assume, of course, for the presence of Jupiter is the reason for their existence. They can be seen through field glasses and their varying positions with respect to Jupiter are fascinating. Not all four of them are always visible at the same time. It often happens that one or more of them is either passing beyond Jupiter from the viewpoint of the Earth, or is between Jupiter and the Earth and is indistinguishable against the bright background of the surface of Jupiter. It is not at all unusual for an observer to find one of them emerging from the shadow cast by Jupiter away from the Sun, or to see one of them suddenly disappear as it begins its passage beyond Jupiter. The positions of the satellites are given in many astronomical publications for each night of the year, so that an observer may choose a time to watch when these celestial chickens are in their most interesting positions around the celestial hen—or rooster in this case.

The other eight satellites do not have names but have been given Roman numerals in order of their discovery. V is nearer to Jupiter than the four brighter satellites and was discovered in 1892 by E. E. Barnard. It is much smaller than its neighboring satellites, with a diameter estimated at



**The orbits of Jupiter's satellites.**

about 100 miles. It is the swiftest in motion of the twelve, which is natural since it is the nearest of all to Jupiter. It skims around the planet at the rate of 1,000 miles a minute.

The sixth and seventh satellites were found by Charles D. Perrine at the Lick Observatory in 1904 and 1905. They are outside the orbits of the four large satellites and are also very small. VI has a diameter of about 100 miles, but VII is less than half that size. VIII was found by P. Melotte at the Greenwich, England, Observatory and is about the size of VII. IX is farther from Jupiter than VIII and is one of the four discovered by Seth Nicholson of the Mount Wilson Observatory over a number of years. Nicholson found IX in 1914. Then in 1938 he discovered X and XI, which are between VII and VIII in position. He found XII in 1951. All four of these last are tiny, between 15 and 20 miles in diameter.

The four outer satellites, XI, VIII, IX, XII, must be considered as a class by themselves. They revolve about Jupiter

in a direction contrary both to that followed by the other eight and to that in which most of the satellites of the solar system revolve about their primaries. The Earth's Moon, Phobos and Deimos of Mars, and the eight satellites nearer Jupiter all move in the direction in which the planets rotate—in the direction we call from west to east on the Earth—or, as we see these satellites from the Earth, from left to right on the Earth side of their planets and from right to left on the far side of their planets. These four rugged individualists, however, move around Jupiter in a direction counter to Jupiter's rotation, from east to west. The nearest of these four satellites to Jupiter is XI, about 14,000,000 miles from Jupiter, and the most distant is XII, more than 15,000,000 miles from Jupiter. Their distances and the periods of their orbits are a bit indefinite because the attraction that Jupiter holds over them is greatly weakened by these same distances and they are considerably affected by the gravitational influence of the Sun.

The reason for the retrograde motion of the four little members of Jupiter's family is not known. One theory has been advanced that these are not natural satellites of the great planet, but are asteroids, captured by Jupiter's strong gravitational pull from the belt of asteroids that lies generally between the orbits of Mars and Jupiter. They are, if this is true, adopted satellites.

The four larger satellites were discovered by Galileo Galilei in 1610. Galileo's story of their discovery and his realization of the implications of this family is one of the fascinating annals of astronomy. On January 8, 1610, Galileo looked at Jupiter through one of the crude pioneer telescopes that he had built himself, and saw what he thought were three faint stars, two to the east and one to the west of the planet, and all of them about on the same line. Cloudy weather prevented his repeating his observations for a few nights, but when he looked again, the three stars were all

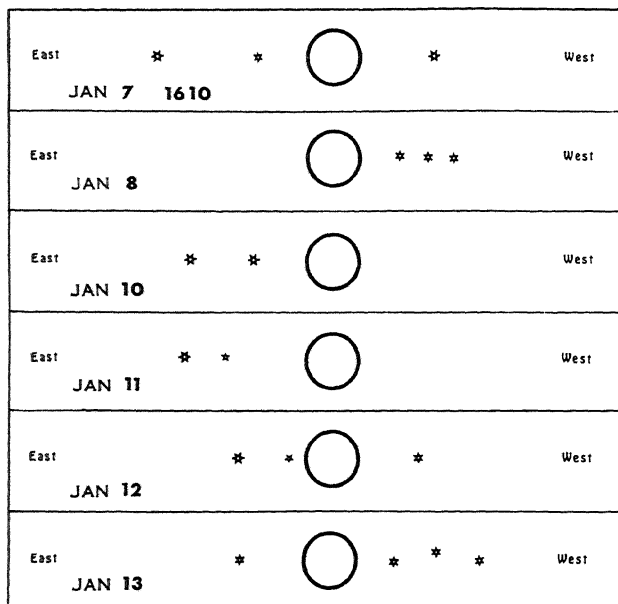


**Diagram shows Galileo's discovery of the four largest satellites of Jupiter.**

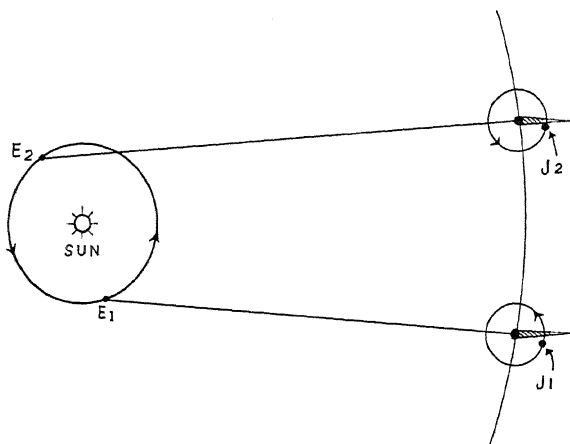
on the west side of Jupiter. Two nights after this, only two of the stars were visible, and they were both again on the west side of the planet, but later that same night a third star appeared. On January 20 Galileo found a fourth tiny star, a little out of line with the others. Galileo realized then that these tiny stars, as he first called them, were satellites gravitationally controlled by Jupiter and revolving around Jupiter at fantastic speeds. Their presence and behavior did much to convince him of the essential truth of Copernicus' theory that the Sun had a similar family and that the Earth was a captive planet revolving around it and not the center of the system. Galileo called the four bright satellites the Medicean stars, after the family to which his Florentine patron belonged, but they are now often called the Galilean satellites.

The masses of these four satellites can be calculated by the perturbations of their orbits in relation to each other and to

Jupiter. The ratio of their sizes and masses will give their densities. Io and Europa have densities that do not differ widely from the density of the Moon, and they are probably made of rock. Ganymede is less dense and must be a combination of rock and ice, while Callisto has a density less than that of water and may be all ice. All four of them are individually much better reflectors of light than the Moon, but they are all so much more distant from the Sun that they do not have as much to work with as the Moon has. With this disadvantage they probably do not give Jupiter as much as one third of the light that the Earth receives from the full moon, even when they are all working together. As far as the outer satellites are concerned, VI is the only one that could be seen from Jupiter itself without a telescope.

The various aspects of the four bright satellites was the cause of one of the great discoveries of astronomy. In 1675 Ole Roemer, a Danish astronomer whose first name may sometimes be seen latinized as Olaus, was timing very carefully the passages of these satellites into and out of the shadow cone of Jupiter. Over a period of time Roemer noticed that these eclipses of the satellites by Jupiter occurred much later when Jupiter was near conjunction than when it was at opposition. In one case, of course, Jupiter would be on the opposite side of the Sun from the Earth and more distant from the Earth by the diameter of the Earth's orbit than when it was in opposition, on the same side of the Sun as the Earth.

Roemer reasoned that the difference in timing of the eclipses of the satellites was caused by the greater distance that had to be traveled by the light making the eclipses visible to him. His timing, with the instruments available to him at that date, made this difference  $16\frac{1}{2}$  minutes and gave him a figure for the velocity of light of approximately 186,000 miles a second. Refinements of measurement have brought this figure to 186,324 statute miles a second, which is the fig-



**The greater distance between  $E_2$  and  $J_2$  than between  $E_1$  and  $J_1$  forced light to travel farther and made satellite eclipses late.**

ure published in the *American Ephemeris*. This has turned out to be a most important figure in modern science: it is the velocity of radiation in a vacuum. One form of radiation we see as light, and the figure for the velocity of light is now accepted as a constant, unaffected by the motion of either the source of light or the base of observation, or both. This constant has been given the symbol "C." This is the "C" in Einstein's famous equation " $E = MC^2$ ," which is explained in Chapter 4.

This, then, is the giant of the solar system: Jupiter, with a mass more than twice that of all the other planets put together; the largest object, apart from the Sun, in the system. Beyond Jupiter the distances between the objects in the solar system begin to expand. Jupiter is more than three times as far from the Sun as Mars is. This does not take into account the belt of asteroids that is generally halfway between the Sun and Jupiter. Mars, in turn, is one and a half times as far from the Sun as its next inner neighbor, the Earth; and the Earth is about half as far again as Venus, which is almost twice as far as Mercury. Beyond Jupiter the distances



between the planets are prodigious, but the ratio of intervals is a bit less. Saturn is not quite twice as far from the Sun as Jupiter; Uranus is a little more than twice as far as Saturn; Neptune is one and one half times as far as Uranus; and Pluto is one and one third times as far as Neptune.

Less than a hundred years ago it was unthinkable that all of the planets were not occupied by intelligent beings. An astronomical text in wide use in 1840 goes into a long discussion of the possible ideas and conceptions of the Jovians. Our greater knowledge of conditions on the other planets and of the requirements for life has drawn a curtain over this sort of speculation. From Mars outward is forbidden territory. Here are the prodigious giants, moving in dreadful cold, afflicted by turmoils in dense and poisonous atmospheres, atmospheres that are strong enough to carry the thunder of their storms across hundreds of millions of miles to register on instruments on Earth. Here is no goal for travelers. Perhaps a landing might be made on one of the Galilean satellites, and a close view of the great, cloudy shroud of Jupiter may yet be seen from such a vantage point. It might almost be worth the journey.

## Saturn

FOR THOUSANDS OF YEARS there were five planets known in the solar system. Then in 1543 the Earth was added to the group, although man was reluctant for many years to accept Copernicus' nomination of the Earth into membership. Last of the charter members was Saturn, to original observers the slowest moving of all the planets. Saturn is the most distant of the visible planets. Between Jupiter and Saturn lies a void that is as wide as the gap between Mercury and Jupiter—a gap in which travel three planets and countless asteroids. Between Jupiter and Saturn, however, is space—space only rarely invaded by an occasional comet. Saturn is at a mean distance from the Sun of 886,300,000 miles. This is the middle point between a perihelion of 839,000,000 miles and an aphelion of 937,000,000 miles. The difference between these two extremes of distance is almost 100,000,000 miles—somewhat more than the mean distance between the Earth and the Sun. Only three other planets have orbital eccentricities relatively greater than that of Saturn—Mercury, Mars, and Pluto. Saturn requires twenty-nine and one half years to accomplish one trip around this tremendous orbit.

The oblateness of the visible disk of Saturn furnishes a strong clue to the construction of the planet. The flattening of Saturn's poles is greater than that of any of the other planets in that the equatorial diameter of the planet exceeds

its polar diameter by nearly 10 per cent. The actual factor is  $1/9.5$ . Saturn's equatorial diameter is 75,021 miles, and its polar diameter is 67,805 miles. The difference of 7,216 miles is only slightly less than the diameter of either Venus or the Earth. Saturn's mean diameter—the halfway mark between the two extremes—is 71,500 miles. This places Saturn in second position among the planets as far as size is concerned, but the amount of material the planet contains—its mass—is strangely low and accounts for its large oblateness. Saturn's mass is only 95 times that of the Earth in spite of its having 763 times the volume of the Earth. Saturn's density is less than three quarters of the density of water, and Saturn would float if a body of water could be found large enough to accommodate it.

These features—its extreme oblateness, its small density, and its large volume—have caused considerable speculation about the physical structure of Saturn. Again, Rupert Wildt, the Yale astronomer who described the widely accepted physical model of Jupiter, has constructed a hypothetical model of Saturn. He has pictured Saturn as a body of whose radius 35 per cent is taken up by a central core, 20 per cent by a sheath of ice surrounding this core, and 45 per cent by an enveloping atmosphere. These percentages translated into miles make the solid planet about 25,000 miles in diameter, the sheath of ice about 7,000 miles thick, and the atmosphere about 15,000 miles deep. Other astronomers picture the atmosphere as much deeper, with a corresponding shrinkage of both solid core and ice sheath, and still others build a planet made entirely of gas, increasing in density from surface to center under enormous gravitational pressure, but entirely without a solid core.

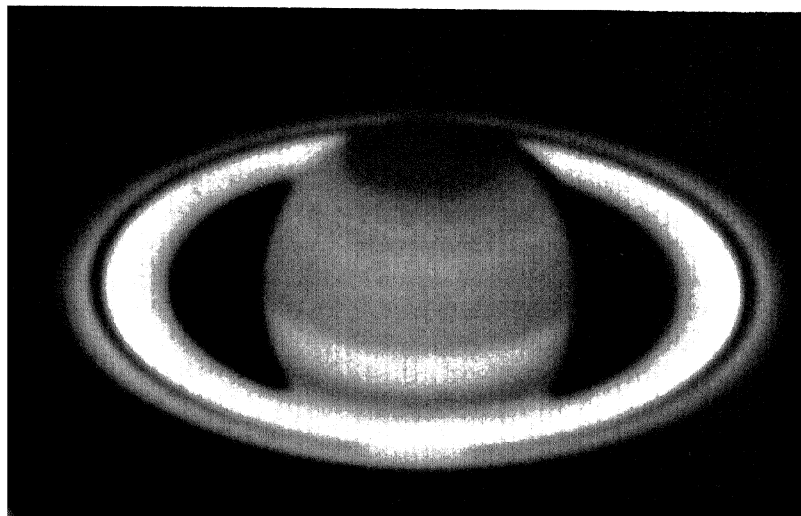
Saturn's small mass gives it a surface gravity of only 1.17 times that of the Earth. There would also be a variation in this force of about 30 per cent, as measured at the poles of Saturn, above the gravitational pull of the planet at its equa-

tor because of the shorter distance from its center to its poles.

At Saturn's distance from the Sun, its surface temperature should be about 300 degrees below zero Fahrenheit. Since ammonia would be frozen into crystals at this temperature, the ammonia that is obviously present in the atmosphere of Saturn must lie as an unpleasant snow on the surface of the icy sheath below an atmosphere composed largely of methane. An analysis of sunlight reflected from the clouds that surround Saturn show considerably less ammonia than does the atmosphere of Jupiter, while the evidence of methane is much stronger. Since both of these gases are combinations of hydrogen, that ubiquitous element must figure largely in Saturn's economy.

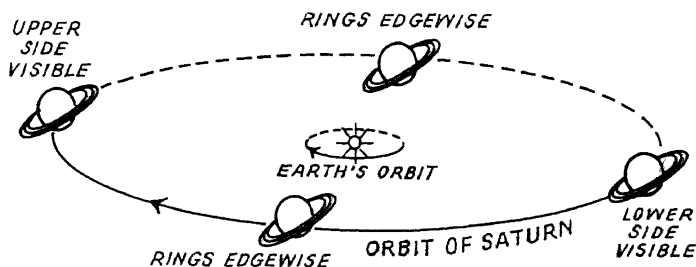
Seen through telescopes from the Earth, the visible surface of Saturn shows cloud bands similar to those on the surface of Jupiter, but not as conspicuous or as highly colored. This more subdued effect may be due to the greater distance across which Saturn is seen. A few whitish spots have appeared from time to time to mar the symmetry of Saturn's cloud bands,

**Saturn showing faint cloud bands; two of the components of its ring system separated by the Cassini Division.**



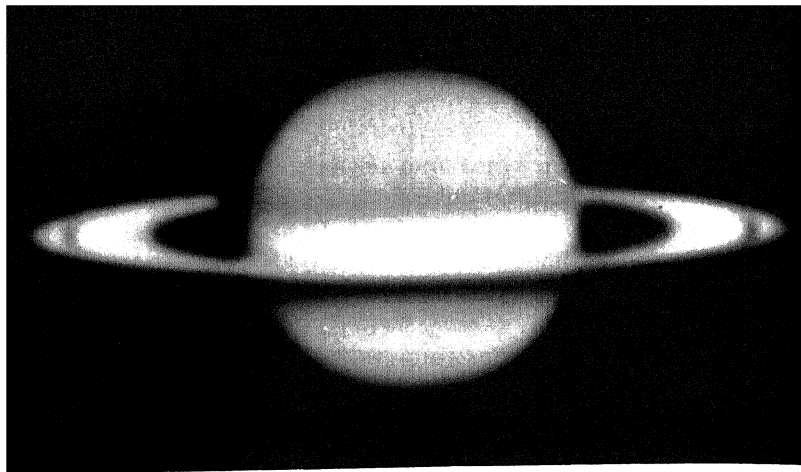
but these spots are less prominent and distinctive than those that have appeared in the atmosphere of Jupiter.

Saturn's albedo—its ability to reflect sunlight—is slightly less than that of Jupiter—42 per cent against 44 per cent. The seasonal changes in brightness that are seen on Saturn are small and are probably caused more by the different angles at which we see Saturn's ring system than by the varying distances through which we see the planet itself. The polar axis of Saturn is inclined from a vertical to the plane of Saturn's orbit by 26 degrees 42 minutes, and the plane of



**Saturn's rings are seen at various angles through the period of Saturn's revolution.**

Saturn's orbit is inclined from the ecliptic by  $21\frac{1}{2}$  degrees. These two figures added together tell us that Saturn's equator is tilted by 28.1 degrees from the ecliptic. As Saturn goes around the Sun, then, we see the rings at times at an angle of 28 degrees, but at other times they present themselves edge on to our view. These two differing aspects of the rings occur at intervals of about half Saturn's orbital period, or about every fifteen years. At the open intervals, when the rings are seen at their highest angle and are most visible, we look first at one surface of them and then, at the next open interval, at the other, so that we see alternately what might be called their upper and their lower surfaces.



**Saturn at a less favorable angle.**

It is when the rings are open that Saturn appears brightest to us, for the rings at this angle reflect more than one and one half times as much light as does the planet alone. At alternate times, when Saturn's inclination and position present the rings to us edgewise, they all but disappear. Only in the largest telescopes can they be seen at all at such times and then only as a fine, bright line crossing the disk of the planet. From this evidence it is estimated that the thickness of the rings can be only about 10 miles. The last edgewise presentation was in the fall of 1950, and the next will occur in 1965, early in the year. In 1958 the rings were favorably presented, but they have since then lost some of their breadth and brilliance.

It is not possible to distinguish Saturn's rings without a telescope, so nothing was known of them until 1610. Galileo saw them first, but during the years in which it was possible for him to observe Saturn, the planet was unfavorably inclined and the rings were nearly closed. Galileo's telescopes also left much to be desired as aids to observation. He could see that there was something strange about Saturn, and he described what he saw as three bodies—a large central planet with two tiny satellites clinging to it, one on either side—a sort of Saturn with ears. Soon after this first glimpse, Saturn

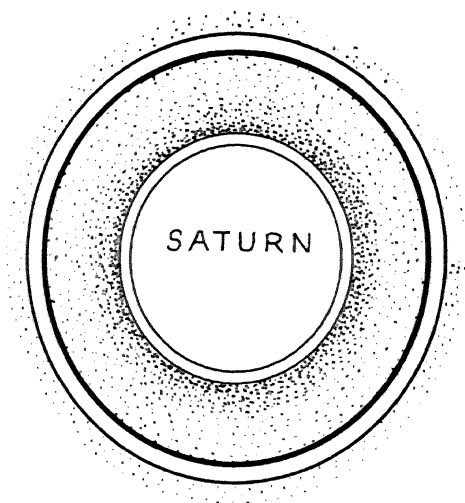
must have reached the peak of its unfavorable inclination, and Galileo could find no trace of the rings—or, as they seemed to him, of the two small satellites clinging to Saturn. He reported sadly that Saturn had swallowed its children according to the mythological precedent. It was not until 1655 that Christian Huygens, a great pioneer whose principles are still standard in telescopic eyepieces and who invented the pendulum clock, was able to see and describe the ears that Galileo had seen as a bright ring that went completely around the planet.

In 1675 Giovanni Domenico Cassini, a French astronomer of Italian origin, had been observing Saturn in his post as director of the Paris Observatory, to which he had been appointed by Louis XIV. He found a division in the ring, a dark line that separated the ring into two concentric parts. In 1850 George Bond, at the Harvard University Observatory, first saw a faint section of the ring system lying inside the brighter parts of the ring, nearest the planet itself. The outermost ring is about 171,000 miles in diameter, and this figure may be considered the diameter of the entire ring system. The outer ring is about 10,000 miles wide. Then comes the Cassini Division, a dark line about 3,000 miles wide. Inside of this is the middle ring, brightest of all the various segments. This middle ring is about 16,000 miles wide. There is a much narrower and less easily discernible division between the middle ring and the faint innermost ring discovered by Bond. Bond's ring is called the crape ring because of its resemblance, when seen through a telescope, to the crinkly dress material called crape. The crape ring is about 11,500 miles wide, and the narrow division that separates it from the bright middle ring is about 1,00 miles wide. The inner edge of the ring system is about 7,000 miles above the visible disk of Saturn. Almost every other word in this paragraph is "about," because all measurements of astronomical distances must be approximate, and an appropriate hedge must be raised against categorical assertions.

Through the years the composition of Saturn's rings has become known by a fascinating accumulation and evolution of knowledge about them. First of all, the rings cast shadows on Saturn's disk at certain times when sunlight strikes them at favorable angles. The shadow of the outer ring is fairly dense; the Cassini Division casts no shadow, but allows the light to pass unimpeded; the bright middle ring casts a deep shadow; and the crape ring, a mottled, spotted shadow. When one of Saturn's satellites passes in our line of sight beyond the ring system on its way around the planet, it is almost hidden by the outer ring; completely visible in crossing the Cassini Division; hidden again in passing beyond the middle ring; and slightly dimmed during its passage behind the crape ring. All of these bits of evidence indicate that the rings are composed of small separate particles. As further evidence of this, the spectrum of the ring system shows a Doppler effect which could be produced only if the inner portion of the ring system were revolving about Saturn at a greater speed than those parts of it farther from the planet. The reverse would be true if the ring system were one solid mass. Further, James Clerk Maxwell, the great Scottish physicist, proved in a brilliant paper written in 1859, that a solid ring about Saturn could not endure but would be broken up, while a ring composed of relatively small particles could remain intact if the total mass of all the particles were small enough. The mass of Saturn's rings fits Maxwell's formula, and the rings remain, composed of fragments of dust, stone, metal, and probably ice.

Even the outer satellites of Saturn have a hand in dictating the appearance and arrangement of the rings. The Cassini Division and the minor division, which, by the way, is known as the Encke Division, lie at critical distances from the surface of Saturn in relation to the periods of Saturn's satellites. Mimas, the satellite nearest the outer edge of the ring system, is probably responsible for the Cassini Division.





#### **The structure of Saturn's ring system.**

It has been found that the gravitational influence of a body of the mass of Mimas will prevent the presence of any particles at distances from Saturn that correspond to simple fractions of the period of such a satellite. The Cassini Division is at a distance that corresponds to one half of the period of Mimas, and the resonance effect of the gravitational field of Mimas would sweep clean the region of the Cassini Division. Other minor divisions in the ring are at corresponding distances which relate to the periods of revolution of Mimas and of others of Saturn's satellite family.

The existence of the ring system probably depends upon a physical law first stated by a French astronomer, Edouard Roche. Roche showed that the tidal force of a planet acting upon a much smaller body within a critical distance of the planet would tear the smaller body into bits. At first it would appear that the planet would pull the smaller body intact to its surface, but the tidal pull would be stronger at the surface of the satellite nearest the planet, so that the satellite would be broken up and its fragments scattered piecemeal around the planet. Roche's critical distance is 2.5 times the radius

of the planet. In the case of Saturn, the ring is within Roche's limit. If a possible tenth satellite of Saturn had ever come as close to Saturn, it would have been torn to bits by the forces of the mother planet and its remains distributed around Saturn as we see them. It may be that Galileo's lament for the children of Saturn was not as farfetched as might be thought.

Saturn has a family of nine known satellites, all revolving about it in orbits that lie farther from Saturn than does the ring system. This must be so if the satellites are to remain intact. All but two of Saturn's satellites, however, lie within 1,000,000 miles of Saturn, and three of them are nearer to Saturn than the Moon is to the Earth. This circumstance lends weight to the possible origin of the ring system. The largest of Saturn's satellites is Titan, sixth in order of distance from Saturn but first in order of discovery. Titan is 2,600 miles in diameter—larger than the Moon and almost as large as Mercury. Titan was discovered by Christian Huygens in 1655, in the same year in which Huygens discovered that the two "ears" of Saturn that Galileo had seen were really parts of the ring. Titan stands out among all the other satellites of the solar system in possessing an atmosphere. It seems remarkable that so small an object should have sufficient gravitational authority to hold an atmosphere upon its surface, but there are two strong indications that it has at least a trace of atmosphere. Titan's color is orange, similar to the basic color of Mars and for the same reason. It may be that the surface material of Titan has been oxidized, or rusted, by the chemical action of an atmosphere, as the surface of Mars is believed to be. Gerard Kuiper has also been able to identify the molecular bands of methane in the spectrum of sunlight reflected from Titan. It is just possible that some of the heavier combinations of gases could remain frozen on Titan at its great distance from the Sun and with its consequent low temperature.

The satellites closer to Saturn than Titan have extremely

high albedos—higher even than that of Venus. From this evidence, together with their exceedingly small masses, it is suggested that they may be composed largely of ice. Only one of these satellites is larger than 1,000 miles in diameter. This is Rhea, with a diameter of about 1,100 miles. The rest are tiny, but there is a strange relation between their sizes and their distances from Saturn. The farther they are from Saturn, the greater are their diameters. Nearest to Saturn is Mimas, 400 miles in diameter and about 115,000 miles from Saturn. Then in order come Enceladus, 500 miles in diameter and 148,000 miles in distance; Tethys, 800 miles in diameter and 183,000 miles in distance. Titan, with its 2,900-mile diameter, is next beyond Rhea—in fact, twice as far from Saturn—759,000 miles as against Rhea's 327,000 miles. Beyond Titan is Hyperion, a mere 300 miles in diameter but 920,000 miles from Saturn. Iapetus is the first of Saturn's satellites to lie more than 1,000,000 miles from the planet. Its diameter is about 1,000 miles, and it is at a mean distance from Saturn of 2,210,000 miles. Then comes a gap of almost 6,000,000 miles before Phoebe, smallest and most distant of the satellites. Phoebe is about 200 miles in diameter and is 8,034,000 miles from Saturn. Like the four outermost satellites of Jupiter, Phoebe has retrograde motion, revolving about Saturn in a direction opposite to that of Saturn's rotation, and may be a captured asteroid.

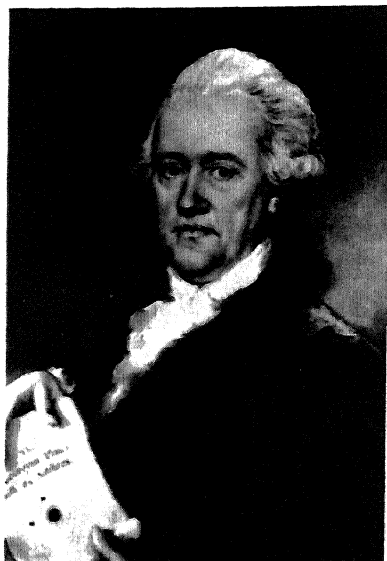
Phoebe was discovered in 1904 by W. H. Pickering, who announced at the time that the photographic plates that contributed to the discovery of Phoebe showed a tenth satellite which, however, was nearer to Saturn at times than Hyperion and almost at the same distance as Titan. This tenth satellite was christened Themis, and at the time of its discovery, Pickering expressed fears that it was too close to Titan for comfort and that something might happen to it. Perhaps it did, for Themis has not been picked up since, and Saturn is credited now with only nine satellites.

## Uranus

BY THE MIDDLE of the eighteenth century, man was perfectly happy with the solar system. It was a snug little arrangement which he had been able to see well enough even before the telescope was devised. It had a more or less central Sun to hold all its members together and to keep them well organized. It contained six planets, all moving about the Sun, and there were nine satellites attached by gravity to three of these planets. There was an occasional comet and some meteors. Of course, man's ideas of what these things really were and how and why they behaved had undergone certain changes since the beginning of his observation of them. Copernicus, Galileo, Kepler, Halley, and Newton had solved some of the more obvious riddles and had straightened things out so that the solar system was one big, well-organized family. Then a young German who had been living in England for a few years, making his way as an organist and teacher and composer of forgettable little tunes, became interested in the heavens as a means of relaxation.

Friedrich Wilhelm Herschel brushed up on his mathematics and turned his really remarkable mechanical skill to astronomy. He was not able to buy the sort of telescopes he wanted, so he built his own, and, unlike most builders of telescopes, he looked through them. With the methodical and unhurried manner of doing things that has come to be

**Sir William Herschel**  
**(1738-1822)**



an attribute of the Teutonic temperament, he looked at the sky. He did not skip from one celestial wonder to the next, as do most beginning observers. He set himself a program and adhered to it. He was going to examine every star, every object in the sky that his telescope would reveal to him. He had built himself a big telescope for he wanted to bring to his eyepiece all the light that he possibly could. His was a reflecting telescope with a mirror fashioned out of speculum metal—a combination of copper and tin which required frequent laborious polishing and adjusting. His instrument was made from a pattern of his own devising and was a bit different from other reflectors. Normally a reflector is built with a mirror that has been highly polished and ground to a parabolic surface and is set in the lower end of the telescope tube. Such a mirror will reflect the light from a star so that the light is brought to a focus near the upper end of the tube. In most reflectors a plane mirror is set at an angle of 45 degrees just below the point at which the light comes to a focus, and the cone of reflection is picked up there, is diverted to one side, and passes through a hole in the upper

part of the tube where an eyepiece is placed so that the image may be examined.

Herschel's mirror, instead of being set at the bottom of the tube at right angles to the long axis of the tube, was canted slightly so that the focal point of the mirror fell just inside the upper edge of the tube. Herschel placed the eyepiece there, stood with his back to the object he was examining, and peered over the edge of the tube like a small boy looking down a well, watching the sky. He set himself the task of examining the sky by dividing the celestial sphere into strips 2 degrees wide. Then he marched slowly along each strip from horizon to horizon, locating and describing every object that came into the field of his telescope. When he had completed one strip, he began another. His sister Caroline, according to the story, sat in a lighted room next to his observing chamber, noting down every word that Herschel dictated.

In 1781, during one of these telescopic peregrinations, Herschel found an object that did not have the visual characteristics of a star. It had an apparent disk and a greenish tinge. Herschel put it down as a possible comet in its early stages of development, and sought it again on the following night to see what might have happened to it. If it had changed its position at all from that in which he first saw it, it must be relatively near the Earth. This would happen if it were a comet. It had moved, but it was not a comet as Herschel had first suspected. Many subsequent observations disclosed the nature of the little greenish disk. It was a planet. Herschel published the story of his discovery, and it was soon confirmed. Herschel wished to call his new planet Georgium Sidus—"George's Star"—in honor of George III, king of his adopted country. George was not very popular, however, and neither was Herschel's idea. Herschel's fellow astronomers called the new planet Herschel for a number of years, but finally Johann Ehlert Bode, who was editor of the *Astronomisches Jahrbuch* and an influential man in astronomical

circles, suggested that it should be named more in keeping with the other captives of the Sun. He nominated Uranus who, in Greek mythology, represented the whole of heaven and was the father of Saturn.

In finding Uranus, Herschel more than doubled the diameter of the solar system and, although he was not aware of it, set in train a series of events that resulted in the discovery of two more planets years later. Herschel was plummeted into fame by his discovery, and he remained famous owing to his methodical methods of observation. He declared later that he had examined five times every object that his telescopes would reveal to him, and the list of his discoveries, particularly of distant clusters and nebulae, ran into the thousands.

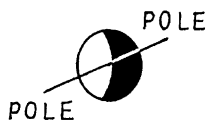
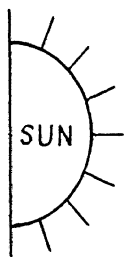
Uranus is the seventh planet in order of distance from the Sun. Its visual magnitude is 5.7, slightly too faint to be seen without a telescope. Through a telescope Uranus presents a disk with a vague outline and is faintly green in color. A large telescope may show faint cloud bands crossing the disk, but these are not always apparent. According to Gerard Kuiper, the mean diameter of Uranus is 29,500 miles. It is oblate to a degree that falls between the oblateness of Jupiter and that of Saturn, which indicates a difference of about 7,000 miles between its equatorial and polar diameters. The mass of Uranus is 14.54 times the mass of the Earth, so that its density is slightly more than one quarter of the density of the Earth. In spite of its size, the surface gravity of Uranus is only 1.05 times the surface gravity of the Earth.

There is an enormous gap between Uranus and Saturn, its nearest sunward neighbor. Uranus is more than twice as far from the Sun as Saturn. Its mean distance from the Sun is 1,784,000,000 miles, and the eccentricity of its orbit is sufficient to cause a difference of almost 168,000,000 miles between its perihelion and its aphelion. It moves along its orbit at a mean velocity of 4.22 miles a second, consuming eighty-

four years and four days in one complete revolution about the Sun.

At the distance from the Sun where Uranus travels, the amount of light and heat it receives is so small that the surface temperature of the planet must be about 350 degrees below zero Fahrenheit. Many of the elements of its atmosphere would be frozen at this temperature, and only a few, such as methane and hydrogen, could remain there as gases. Methane must predominate and is the source of the greenish appearance that Uranus presents. Uranus resembles Jupiter and Saturn in that it rotates rapidly, turning upon its axis every 10 hours 48 minutes.

These facts do not reveal any particular distinction for Uranus, but when man learned the degree of the inclination of its axis of rotation, he found cause for considerable speculation. Uranus is inclined by 98 degrees from a vertical to the plane of its orbit about the Sun. This means that Uranus



**The polar axis of Uranus is inclined 98 degrees from the plane of its orbit.**

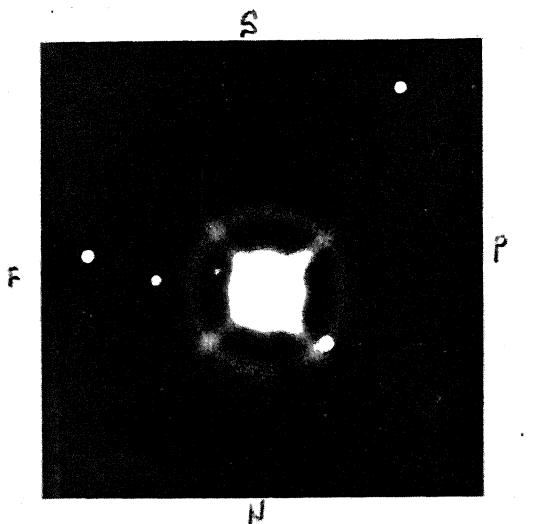
is more than lying on its side as it revolves: it is standing on its head. The strange size of its angle in inclination was determined by accepting the direction of rotation of Uranus as normal and direct, and then applying that direction of rotation to the position of its axis. As is the case with the other



planets, the poles of Uranus are relatively fixed in their direction and point always to the same part of the sky. These peculiarities provide Uranus with a fantastic year. Let us begin at the time when Uranus' north pole—so called by analogy with the north pole of the Earth, from which the rotation of the planet appears counterclockwise—is pointing at the Sun. For the next twenty-one Earth years, Uranus moves through one quarter of its own annual journey, swinging wide of the Sun as far as the extensions of its north pole are concerned, until, at the end of that time, it is so situated that the Sun may be said to be over its equator.

The next twenty-one Earth years will be spent in reversing this process until the Sun shines over the south pole of Uranus. The third season will pass while Uranus travels around the Sun until the Sun is again over its equator, but the planet is on the opposite side of the Sun from where it was forty-two Earth years before. The final twenty-one Earth years will bring it back to its original starting position. Thus, the alternate seasons will place the Sun over its north pole, over its equator, over its south pole, again over its equator and finally come full cycle over its north pole again. If the Sun were as near to Uranus as it is to the Earth, such a journey would cause a tremendous alternation of temperature and periods of light and dark, but at the distance of Uranus from the Sun, the questions of seasons and night and day are purely academic. During the periods of polar presentation to the Sun, the poles of Uranus have continuous day at the sunward end and continuous night at the dark end. The alternate seasons will be more normal by Earth standards as far as the position of Uranus is concerned, since the Sun will be slowly making an apparent journey from one pole to the other, and the planet would produce a series of short days and nights by reason of its rapid rotation.

Herschel himself found two large satellites of Uranus about six years after he had discovered the planet. These satellites



1948 March 1, 2:46 U.T. Exp. 37.

**Uranus and its five satellites. Uranus, overexposed, showing reflections from telescope mirror supports.**

are called Titania and Oberon after the king and queen of the fairies in Shakespeare's *A Midsummer Night's Dream*. Titania is about 1,000 miles in diameter, and Oberon about 900 miles; an exact measurement of these tiny bodies at such a tremendous distance is almost impossible. Two more Uranian satellites were found in 1851 by William Lassell, a retired English brewer and amateur astronomer. They are both nearer to Uranus than is either Titania or Oberon and are about 600 and 400 miles in diameter. They were named Ariel and Umbriel. Ariel is another Shakespearian, from *The Tempest*, and Umbriel is in Alexander Pope's *Rape of the Lock*. In 1948 Gerard Kuiper found still another satellite of Uranus, whose orbit was inside the orbits of all the rest. This is Miranda—like Ariel, taken from *The Tempest*.

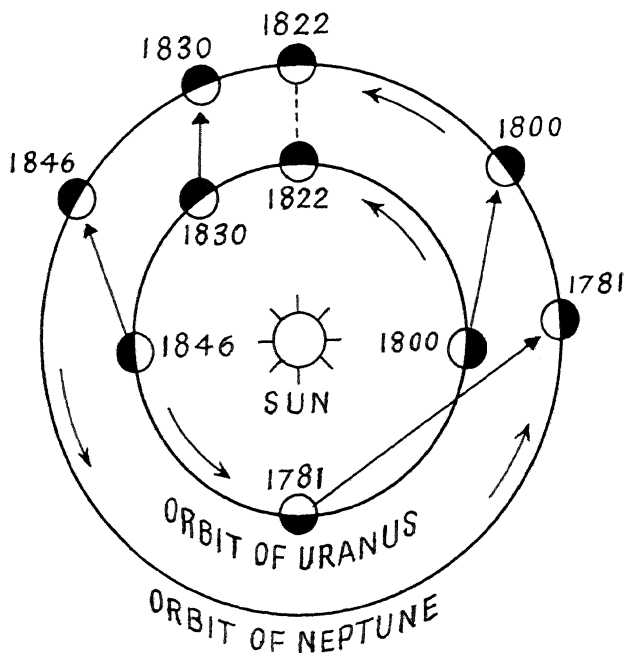
All of the satellites of Uranus revolve about the planet in the same direction as the rotation of Uranus. This is the

pattern followed by most of the satellites of the solar system, and in the case of a more conventionally inclined planet, the motions of these satellites would be considered direct. Because of the great inclination of Uranus, however, its satellites seem to revolve in a direction contrary to that of the normal satellites of the other planets; they are, therefore, considered technically retrograde.

## Neptune

AS SOON AS THE DISCOVERY of Uranus had been confirmed in 1781, its orbit was calculated and the length of its year was determined. Observations of the new planet accumulated, even including some that had been made before its discovery. These predisccovery observations had classified it as a star. The total of all observations gave the angle of the orbit of Uranus to the ecliptic and all of the other various motions and positions that make up what astronomy calls the elements of its orbit. These elements were all worked out and published. The progress of Uranus about the Sun is slow: eighty-four years and four days are required for it to make one revolution. Even after the first curiosity about the new planet had subsided, astronomers watched it perfunctorily. Its position appeared regularly in various astronomical publications, and it became a full-fledged member of the captives of the Sun.

After many years had passed, however, it was discovered that Uranus was straying from the orbit that had been calculated for it. It was not behaving like a well-disciplined planet. By 1845, sixty-four years after its discovery, Uranus was a good 2 minutes of arc off course. Two minutes of arc does not sound like a serious deviation. It is about one fifteenth of the apparent diameter of either the full moon or the Sun and represents 1 part in 10,800 of the circumference of a



**The different velocities of Uranus and Neptune cause a constant change in their relative positions and in the gravitational influence of Neptune upon Uranus.**

circle. If, however, the radius of such a circle is the mean distance between Uranus and the Sun—almost 2,000,000,000 miles—the distance in miles represented by even so minute a deviation is tremendous.

Astronomy tried to find the answer—the influence that was leading the new planet astray. All the known factors were reviewed; the Sun and all of the planets whose forces might affect the progress of Uranus along its orbit were taken into consideration and accounted for. The disturbing influence had to come from something outside Uranus itself—something unknown but with considerable mass. Various theories were advanced, and various candidates for the identity of the

tempter were nominated.

The first possibility discussed was that the laws of gravity were at fault. These laws had been published about 150 years previous and were still not universally accepted. They had been used to calculate the orbit of Uranus, and many astronomers felt that they might not be applicable to such distant bodies. Perhaps, too, a cloud of cosmic dust or gas might lie in the normal path of the planet and be diverting it from its calculated course. It might have collided with a comet. There might be a massive but still unknown satellite belonging to Uranus which had not yet been taken into account because it had not yet been seen. Herschel himself had discovered two Uranian satellites by this time, but Jupiter had then four known companions, and Saturn seven, so that it was possible that Uranus may have been even more generously endowed. There was also the chance that still another planet, more remote than Uranus, could be affecting the new member of the solar system.

The only two of these hypotheses that could be easily proved or disproved were those that dealt with a large but unknown satellite or a more distant planet. The positions of either of these two candidates could be determined mathematically from the direction and the extent of the perturbations of Uranus. Of the two, the additional planet seemed to be the more likely cause. Two young astronomical students, completely unknown to each other, became interested in the problem, and each set about to determine the answer.

John Couch Adams was an undergraduate at Cambridge University in England when he first heard of the difficulties that beset Uranus. He began at once to attack the problem on the assumption that these vagaries were caused by an unknown planet. This was before 1843. In 1845 he had completed his work and had sent a paper describing his method of solution and the location of the hypothetical planet to the director of the Cambridge Observatory. A month later he

sent a similar document to the British Astronomer Royal, Sir George Biddell Airy, at the Greenwich Observatory. Airy believed that the discrepancies in the orbit of Uranus were due to weakness in Newton's laws of gravity, which Adams had used in his calculations. After writing a note to Adams about a point in the document—a note that Adams did not bother to answer—Airy shelved the report and did not make any attempt to verify Adams' theory.

Meanwhile, a young French astronomer, Urbain Jean Joseph Leverrier, was working on the same problem. Leverrier had been educated as a chemist, but his general intellectual brilliance had made it possible for him to accept and to fill most capably the post of professor of astronomy in the Ecole Polytechnique. Leverrier sent his memorandum on the perturbations of Uranus to the French Academy in November 1845, a month after Adams had communicated with Sir George Airy. In June 1846 Leverrier published a paper that gave the possible location of a more distant planet, but did not give its possible orbit or mass. Leverrier's calculated position differed by only 1 degree from the location determined by Adams. This coincidence prodded Airy into action. He urged the director of the Cambridge Observatory to look for the planet, but the charts and equipment available at Cambridge were antiquated, and nothing was found. As a matter of fact, it was later realized that the new planet had been seen twice from Cambridge, but it had not been recognized for what it was.

Leverrier kept on with his work, knowing nothing at all of what was happening in England. On August 31, 1846, he published a second paper in which he gave the mass and possible orbit of the unknown planet. He also wrote to Dr. Johann Galle of the Berlin University, telling him of his theory. Dr. Galle had better charts and a much better telescope than had Cambridge University. He went to work at once to search for Leverrier's planet, and on the night of

September 25, 1846, he found what was apparently a faint star that did not appear on any of his charts. This "star" was about 1 degree from the position predicted by Leverrier for the planet. On the following night the "star" had changed its position sufficiently to identify itself as a planet.

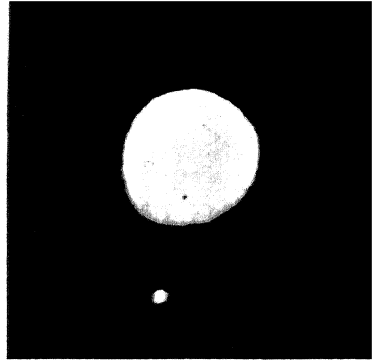
When Leverrier's discovery became known, the British authorities immediately announced the earlier and almost identical calculations of Adams. Sir George Airy published a full account of his own lackadaisical part in the proceedings, and the French screamed Gallic defiance. The only persons who did not take violent sides in the ensuing controversy were Adams and Leverrier, who exchanged amenities and became good friends. Each of them had performed a tremendously difficult and outstanding mathematical feat, and they are both now given credit for the discovery.

For a short time the new planet was called Leverrier, but a name more in keeping with the mythological tone of the names of the other planets was sought, and Neptune was adopted. Neptune's mean diameter of 27,700 miles puts it into the giant class. It is considerably more dense than its neighbor, Uranus, and has a mass of 17.3 times the mass of the Earth. Its mean distance from the Sun is 2,796,700,000 miles. At this distance it receives so little radiation from the Sun that its surface temperature is about 400 degrees below zero Fahrenheit.

Neptune, like the other giants, rotates rapidly. It has a day of 15 hours 48 minutes. It travels its tremendous orbit at a velocity of  $3\frac{1}{8}$  miles per second and spends 164.79 years in making one revolution about the Sun. Neptune's axis of rotation is inclined to the plane of its orbit by  $29^{\circ}.6$  so that—as if it made any difference at that distance—it could have seasons. Its orbit also conforms to the general flatness of the solar system and is inclined to the ecliptic by only 1.8 degrees.

In the year of Neptune's discovery, William Lassell, a wealthy brewer and an ardent amateur astronomer, discov-





**Neptune and its larger satellite, Triton.**

ered an enormous satellite about 220,000 miles from Neptune, making a revolution about the planet in a few hours less than six days. This is Triton, and it may be the largest satellite in the solar system. Its diameter is difficult to estimate accurately, but it is calculated to be at least 3,000 miles. In 1949 the indefatigable Gerard Kuiper found a tiny satellite about 3,500,000 miles from Neptune and named it Nereid.

There is one ironic note about Neptune and its history. Urbain Leverrier, one of the co-discoverers of the planet, a teacher of astronomy, director of the Paris Observatory, lived a full and valuable life for sixty-six years. During all this time, because of either chance or the unfavorable position of the planets, he went from honor to honor and died without ever having seen the planet he discovered.

## Pluto

THE STORY of Pluto really began in 1781, with the discovery of Uranus. After Herschel had found this first "discovered" planet, a search through various astronomical records showed that Uranus had been seen at least twenty times by other astronomers before its discovery, but it had been carefully marked down each time as a star. The locations of Uranus at these various glimpses were so distributed in time that they practically covered the orbit that was calculated for the new planet, but, for some reason, they did not fit together. When all of the various influences that were known to exist had been calculated into a theoretical orbit for Uranus, this theoretical orbit did not take in these random pre-views of it that had been made through the years before its discovery. Uranus moved very slowly along its path, however, so astronomers decided to wait and see how widely the actual orbit differed from the calculated orbit before they made any definite pronouncements.

In 1820, about forty years after Uranus had been definitely shown to be a planet and when it had covered almost half of its orbit since discovery, a new orbit was calculated, based solely upon the known and observed progress of Uranus since discovery. It might well be that the positions astronomers had assigned to Uranus through the years before discovery, when they believed it to be a star, had been erroneous and carelessly noted, but now astronomers had a chance to check

Uranus constantly and thoroughly without any need for dangerous interpolation. To the great frustration of all the learned men, Uranus was not even following this new and carefully calculated course. There must be something, then, that no one knew about out there, dragging Uranus into a path that could not be calculated. A search was begun for such an object. As a result of this search, Neptune was found in 1846, and astronomers heaved sighs of relief and justification, leaned back, and relaxed. But not for long. When the influence of Neptune had been built into the calculations, Uranus was still not following the path it should have been taking. There must be still further unknown influence at work on it.

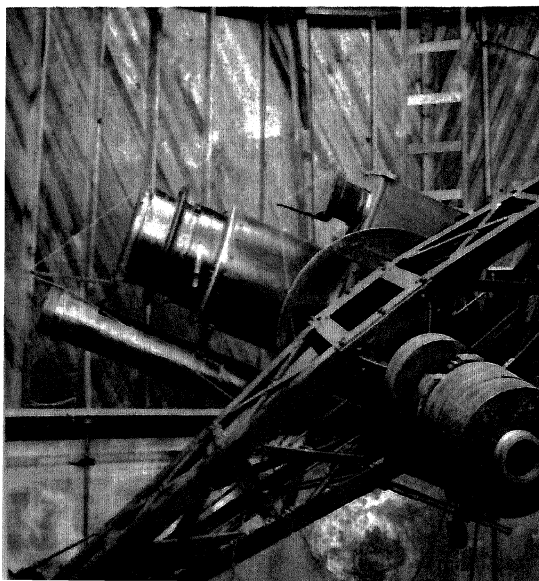
Percival Lowell and William H. Pickering both calculated the possible position of still another planet whose gravitational influence was pulling Uranus out of its calculated orbit. Lowell was the astronomer who had built the Lowell Observatory at Flagstaff, Arizona, some years before, in order to investigate the Martian story. William H. Pickering had assisted Lowell in the selection of a site for his observatory and in its design, and had himself become one of the authorities on Mars.

The presence of still another unknown planet was also indicated by perturbations in the orbit of Neptune. As soon as Neptune had gone far enough along its own path after discovery, it showed signs of deviating from its calculated orbit, very much as had Uranus. Both Lowell and Pickering's calculations of the possible location of this unknown planet were so much in accord that a search for the disturbing body was justified. Lowell called it Planet X, and a special program was set up at the Lowell Observatory to find it. A search was begun that was to last for many years.

By this time the camera had become one of the most valuable tools of the astronomers, and photographs were taken of the sky both above and below the elliptic in the region where both Lowell and Pickering had calculated that the unknown

stranger might be. This was done because Planet X appeared to be wandering farther to one side or the other of the ecliptic than does the average planet. The work was done sporadically at first, but after Lowell died in 1917, it was practically abandoned for several years. Then in 1929 it was begun again systematically, under the direction of Clyde Tombaugh. Tombaugh was born in Illinois and went to live in Kansas on a farm. He made a hobby of astronomy and built his own telescope, like thousands of boys. He had corresponded with the staff at Lowell Observatory about it, and when it was finished, they asked to see it. They thought so highly of its construction and of the care and skill that had gone into it that they offered Tombaugh, then 23 years old, a post on the staff and assigned him to the Planet X program. A special telescope with an objective diameter of 13 inches was allotted to the task, and thousands of pictures were taken and carefully examined. This was truly a needle-in-a-haystack job,

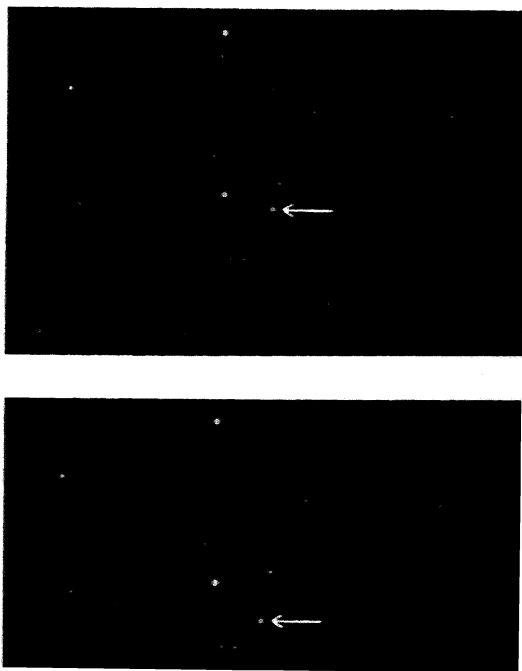
**The telescope that discovered Pluto. The 13", 7",  
5" Clark refractor at Lowell Observatory.**



for the calculated position of the new planet was in the constellation of Gemini, directly in front of a crowded region of the Milky Way. All the plates taken were literally covered with star images, in some cases so close together that scarcely any space background could be seen.

Tombaugh would take a picture of a region of the sky, and after a few nights had passed, he would take a second picture of the same region. The two photographs would then be matched and aligned so that they would show the same part of the sky with exact precision but at slightly different time intervals. Then Tombaugh would examine them through a Blink Comparator. In such a machine two matching photographs are set side by side, and first one and then the other is

**Photographs of Pluto, taken 24 hours apart, showing motion of planet against background stars.**





**Clyde Tombaugh holding discovery plate of Pluto. Taken about a year after discovery.**

illuminated. By this means any object on the plates that has changed its position in the interval between their taking will seem to move. This involves the principle of the motion picture projector—the memory of vision: your eye and your mind unconsciously hold an object in the position in which you last saw it; if you see it again, an instant later, in a new position, it will appear to move. The stars would not move in such a process, but a planet would. After blinking thousands of pictures, Tombaugh found a tiny speck that moved. This was Pluto.

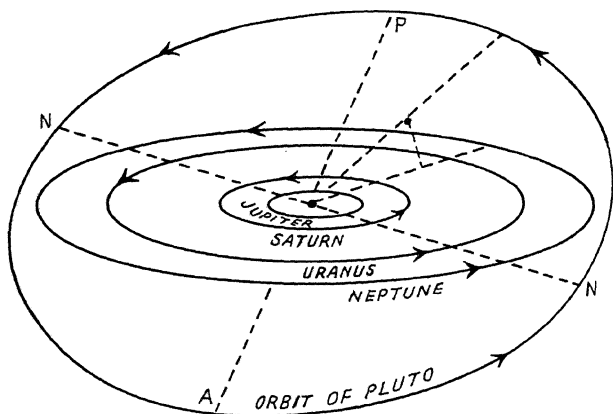
Pluto was named for a god in classical mythology, as are the other planets. The first two letters of “Pluto” are also the initials of the astronomer, Percival Lowell, who had so much to do with its discovery, but who died before that discovery had been accomplished. The discovery was announced on March 13, 1930, the anniversary of Lowell’s birth. The planet’s position, when it was found, was within a short distance of the position that both Lowell and Pickering had calculated for it. Clyde Tombaugh went on in his chosen field. He was graduated from the University of Kansas in

1936 and is still doing valuable work in the exploration of interplanetary space.

Pluto is so distant and consequently so faint that no telescope, no matter how large, will show a disk for it. It is of the fifteenth visual magnitude and cannot, therefore, be seen at all in a telescope with an aperture of less than 14 inches. Its diameter can only be guessed at. Some of the better guesses range from the size of the Earth to slightly less than half its diameter. By building an artificial planet that looked like Pluto when seen through the 200-inch reflector at Mount Palomar, Gerard Kuiper came up with an estimate for the Plutonian diameter of 46 per cent of the Earth. With all this speculation, it should be remembered that whatever is visible of Pluto may be a sort of central highlight on its roughly spherical surface. The faint glow that we see may not cover the entire surface of the planet.

Attempts have been made to calculate the mass of Pluto from the effect of its presence on the motions of Uranus and Neptune. These hints of Pluto's gravitational power indicate a mass for Pluto that is somewhere between 80 and 120 per cent of the mass of the Earth. If Pluto has a diameter of less than half of the Earth's diameter, its volume will be about one tenth of the volume of the Earth. If its mass is equal to the mass of the Earth, it would have to be ten times as dense as the Earth, which is highly improbable. From the evidence to date, two conclusions are possible: either Pluto is much larger than has been estimated, or it is not the object that has been disturbing Uranus and Neptune.

Pluto's orbit is more eccentric and is inclined at a greater angle to the ecliptic than are the orbits of any of the other planets. Pluto's mean distance from the Sun is 3,670,000,000 miles. The eccentricity of Pluto's orbit, however, is 0.249. Its aphelion, then, is 4,589,000,000 miles, and its perihelion is 2,761,000,000 miles. It is almost twice as far from the Sun at the most distant point in its orbit as it is when it is nearest the Sun. At perihelion Pluto is 49,000,000 miles nearer the



**The high inclination of the Plutonian orbit.**

Sun than Neptune, the next planet to Pluto. In spite of this, there is no danger of a collision between the two planets. Since Pluto's orbit is canted at an angle of 17 degrees 9 minutes to the plane of the ecliptic, and the orbit of Neptune at less than 2 degrees, the two planets can never be nearer each other than 240,000,000 miles.

Pluto moves about the Sun in 247 years and 9 months and appears to reach the same relationship of position to the Earth and the Sun in just one day over a year. Its velocity through space along its orbit is a trifle less than 3 miles a second. Dr. Gerard Kuiper, who is making a constant investigation of the planets and of the phenomena connected with them, has recently declared that the rotational period of Pluto is about six and one half days. Since this is much slower than that rotational period of any of the other planets in this remote region of the solar system, it, together with the eccentricity of Pluto's orbit, has led Dr. Kuiper to advance the theory that Pluto was at one time one of the satellites of Neptune. Some unknown but obviously severe upheaval in Neptune's system in the remote past may have torn Pluto from a satellite orbit about Neptune and thrown it into an orbit about the Sun. This theory has given rise to some misunderstanding of Pluto's present status. It may at one time have been a



satellite, but since it is now pursuing a course around the Sun, under the principal gravitational attraction of the Sun, it is by definition a planet, whatever its past may have been.

At Pluto's distance from the Sun, it receives practically no benefit from the Sun in the form of heat and light. The surface temperature of Pluto must be close to absolute zero, possibly  $-450^{\circ}$  Fahrenheit. The albedo of Pluto is 0.16, slightly more than twice that of either Mercury or the Moon, so its surface must be rather dark and dull. No indication of an atmosphere has been found there. If Pluto has the mass that has been attributed to it, its surface gravity should be sufficient to retain about it the elements that make up the atmospheres of comparable planets, but the temperature of Pluto would prevent these elements from forming any sort of gaseous envelope. Anything on Pluto would certainly be in a fairly solid condition. As far as is known, Pluto has no satellites.

This remote particle is the last known planet in the solar system. It is, and probably will remain for many years, a puzzle to astronomy. If it is as small as is now suspected, it must be incredibly dense; and if it is larger than is now believed, its structure may resemble the structures of the other small planets. It may be possible for us to learn a little more about Pluto during the next hundred years, for it will in that time reach its perihelion, which will bring it nearer to the Sun and at times nearer to the Earth. Whether this difference in distance will make Pluto any easier to see is questionable, but it will be better situated for observation than before. In one hundred years Pluto will have completed about half of its orbital travel about the Sun. This may disclose any irregularities that Pluto itself may possess and may give us clues to possible bodies still farther removed from the Sun—perhaps the more massive object that may account more readily for the still dubious perturbations of Uranus and Neptune.

## Asteroids

ON THE FIRST NIGHT of the nineteenth century, Guiseppe Piazzi, an Italian astronomer of considerable note, experienced serendipity. "Serendipity" is a word coined by Horace Walpole to represent that happy condition in which a person who is looking for something fails to find the original object of his search but, in the process of seeking, hits upon something as good or better. Piazzi was guided into the state of serendipity by two German scientists who had been trying to find a formula that would apply to the planets of the solar system: that would account for their sizes and for the distances between them and between each of them and the Sun.

J. D. Titius of Wittenberg, about the middle of the eighteenth century, first undertook this task and seemed to have found a certain rhythm in the arrangement of the planets. Titius' little plan did not become well known until it was espoused by Johann Ehlert Bode, who had made an auspicious beginning as an astronomer in 1766 when he wrote a paper on the solar eclipse that took place that year. A few years later Bode published an elementary text on astronomy and was appointed to a rather indefinite committee whose function was to improve and refine the yearly tables of the positions of the stars and the planets. As a member of this committee, Bode came into contact with Titius' tables and sponsored them. The whole arrangement

is now known as Bode's law.

Bode—or Titius—first set down the names of the planets in order of their distance from the Sun. Underneath the names they placed a series of figures: first, 0; then, 3; each subsequent figure doubled its predecessor. To each figure, 4 was added, and the result was divided by 10. The quotient thus obtained should, according to Bode, closely approximate the distance of each planet from the Sun in astronomical units. An astronomical unit is the mean distance between the Earth and the Sun—about 93,000,000 miles.

When Bode published this interesting little exercise, the known planets were Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Here is the way the table worked out:

| Planet                         | Mercury | Venus | Earth | Mars | ?   | Jupiter | Saturn |
|--------------------------------|---------|-------|-------|------|-----|---------|--------|
| Bode's number                  | 0       | 3     | 6     | 12   | 24  | 48      | 96     |
| Add 4                          | 4       | 7     | 10    | 16   | 28  | 52      | 100    |
| Divide by 10                   | 0.4     | 0.7   | 1     | 1.6  | 2.8 | 5.2     | 10.0   |
| Distance in astronomical units | 0.36    | 0.72  | 1     | 1.52 | ?   | 5.20    | 9.54   |

Less than ten years after Bode had published this law, Uranus was found. It fitted into the scheme with amazing accuracy. The table then read:

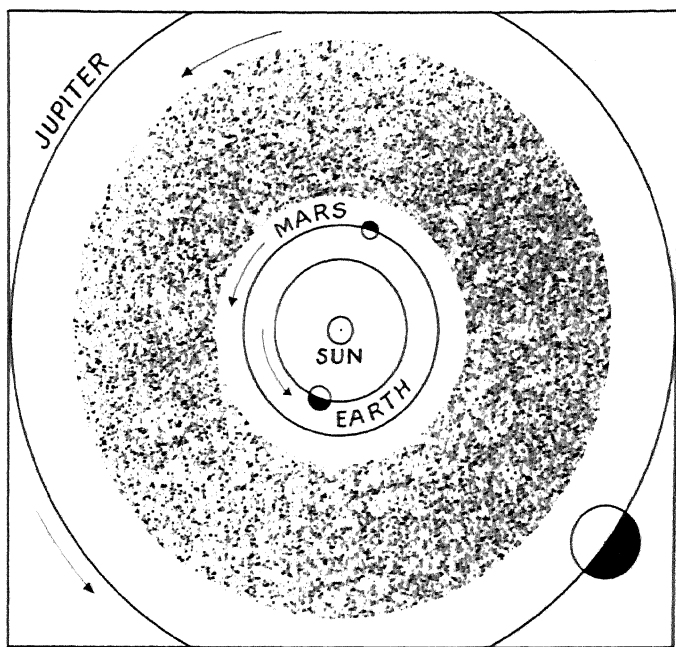
| Planet                         | Mercury | Venus | Earth | Mars | ?   | Jupiter | Saturn | Uranus |
|--------------------------------|---------|-------|-------|------|-----|---------|--------|--------|
| Bode's number                  | 0       | 3     | 6     | 12   | 24  | 48      | 96     | 192    |
| Add 4                          | 4       | 7     | 10    | 16   | 28  | 52      | 100    | 196    |
| Divide by 10                   | 0.4     | 0.7   | 1     | 1.6  | 2.8 | 5.2     | 10.0   | 19.6   |
| Distance in astronomical units | 0.36    | 0.72  | 1     | 1.52 | ?   | 5.20    | 9.54   | 19.19  |

This made all astronomers prick up their ears. In Bode's law there was an obvious gap between Mars and Jupiter where a hypothetical planet bearing Bode's number 24 should be. According to Bode's formula, such a planet's distance from the Sun in astronomical units would be 2.8—slightly more than halfway between the Sun and Jupiter. It may be exaggerating to say that all the astronomers of that time were out scanning the skies to find the missing captive of the Sun

somewhere between Mars and Jupiter, but certainly some of them, when they had completed their daily jobs of measuring tides, casting horoscopes, and the like, hurried to their telescopes and swept the heavens for whatever they might find. Supposedly, the find would be a new planet, probably a small one, since the region in which it was supposed to be was bordered on one side by Mars, a planet smaller than the Earth, although its other border was held by gigantic Jupiter. A planet of any size would have had some difficulty in remaining undiscovered through the long centuries of man's observation of the sky.

Giuseppe Piazzi was no exception to the eager planet hunters. He was gunning for big game, but he succeeded in shooting a snipe at least. Piazzi was preparing a new star catalogue, which was to be an important addition to the literature of astronomy. On January 1, 1801, he discovered what he thought was a comet. The object he saw was faint and very small, and it did not possess any trace of the tail that comets often develop when they approach the neighborhood of the Sun. Since it is radiation from the Sun that is responsible for the tails of comets, Piazzi's find could very well have been a comet that had not yet come close enough to the Sun to be affected.

Piazzi watched this tiny object carefully and even went so far as to write to Dr. Bode, asking him if it had been seen by any other astronomers. Piazzi also reported a change in the direction taken by the object since it was first sighted. Bode had seen other reports of the object but without the detail that Piazzi had given, and he was immediately struck by the position and the velocity of the mysterious stranger. It fitted the gap in his law. It was generally between Mars and Jupiter and was moving in such a way that it would complete a journey around the Sun in four years and eight months. Calculation placed it at a distance of 2.8 astronomical units from the Sun, hitting the gap in Bode's table right in the



**The asteroid belt lies between the orbits of Mars and Jupiter.**

bull's-eye. Bode hoped it would prove to be the eighth major planet of the solar system, but it turned out to be the first of thousands of minor planets, the asteroids.

Giuseppe Piazzi had the privilege of naming his find, once its nature had been determined. He called it Ceres, who was the tutelary deity of his native Sicily. Ceres had a diameter of 480 miles, and its mass was calculated to be about one eight-thousandth of the mass of the Earth. Three more of these tiny worlds were discovered in the next few years: Pallas in 1802, Juno in 1804, and Vesta in 1807. Then followed a hiatus of thirty-seven years until the discovery of Astraea in 1844. After that, as telescopes improved and photography was added to the techniques of astronomy, new asteroids began to pour into the records. There is one story, possibly apocryphal, of a druggist in Paris who bought a small telescope and found

several asteroids in a few months of observing from the back window of his bedroom. Somewhat more than three thousand are now known, and more than two thousand have been confirmed and officially added to the list of the Sun's prisoners.

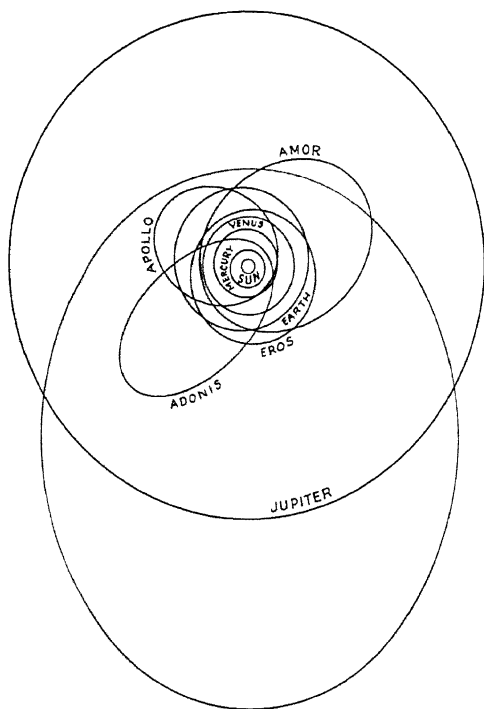
This flood of new members soon resulted in a vast confusion of new names and claims. The whole supervision of asteroids was placed in the hands of the Recheninstitut of Berlin, and certain rules were laid down. The discoverer of an asteroid has the privilege of naming his find, but it is also immediately given a temporary designation until its authenticity has been determined. A double Roman capital letter is assigned to each discovery in such a way that a new series of letters begins on the first and the fifteenth of each month. From January 1 to January 15 of each year, for example, new asteroids are labeled AA, AB, and so on, with the number of the year added. On January 16 the series begins with BA. If more asteroids should be discovered in the two-week period than the lettering system allows for, a subscript is added and the letter series is repeated, as AA<sub>1</sub>. When the orbit of an asteroid has been verified—and this is done by waiting until three perihelion passages have been completed, which may take anywhere from ten to twenty years—and it has been determined that the discovery in question is really a new asteroid and not an old one making its regular rounds, it is assigned a number in order of discovery, which is usually written inside a neat little frame. This final number follows the name selected, within certain limits, by the discoverer. Eros, for example, is listed as "Eros (433)."

Rather stringent rules now exist for the naming of asteroids. Those that were discovered and named before the crowd began to rush in, however, were left alone; they were the charter members and, as such, they had special privileges. Now, if the orbit of an asteroid lies in the region in which most of them travel—roughly between the orbits of Mars and Jupiter—the asteroid must be given a name with a Latin feminine end-

ing, *-a*. This results in some fairly tongue-twisting appellations. One such, named for Dr. Hugh S. Rice, is *Ricea*. Those more daring asteroids whose orbits bring them at times within a smaller distance from the Sun than one astronomical unit, must have names with a Latin masculine ending, *-us*. There is, in addition to these regular members, a special group whose individuals are distributed neatly equidistant from the Sun and Jupiter in orbits that lie rather closer to the orbit of Jupiter than do most of the asteroids. These are called the Trojan asteroids and bear names culled from the classical histories of the Trojan War. At present there are about a thousand asteroids in purgatory, struggling along with their temporary numbers, waiting to be recognized and to be admitted to the inner circle.

Most of the asteroids travel placidly about the Sun at an average distance from it of 2.65 astronomical units. They are not nearly as orderly, as a group, as their larger colleagues, the planets, for many of them have orbits that are much more inclined to the ecliptic than are the orbits of any of the planets. Hidalgo, for example, travels at an angle of 43 degrees to the ecliptic. The orbits of the asteroids are often much more eccentric than those of the planets. Eros can come within 14,000,000 miles of the Earth at one point in its orbit, but it is vastly farther away at another time. Hidalgo has the largest known orbit of any of the asteroids, with an orbital diameter of 531,000,000 miles—about three times the diameter of the Earth's orbit. By contrast, Icarus, most appropriately named, passes only a few million miles farther from the Sun than one astronomical unit when it is at aphelion—farthest from the Sun. When it is nearest the Sun, however, it is inside the orbit of Mercury.

Some of the asteroids have given the Earth a few breathless moments. Adonis, still unnumbered, skimmed to within 1,500,000 miles of the Earth in February 1936. Since Adonis is only about half a mile in diameter, it might not have done



**The orbits of some of the asteroids.**

more damage than to eliminate a couple of major cities, had it struck. In 1937 an asteroid twice as big as Adonis was discovered when it was as near the Earth as Adonis was at its closest, and it was driving in rapidly. This was Hermes. In two days after its discovery, Hermes had plunged to within 500,000 miles of the Earth, coming closer than any other celestial body except the Moon. The orbit of Hermes has been determined only provisionally as yet, but it may follow a path that will at times bring it within 221,000 miles of the Earth.

Ceres is still the largest asteroid that has ever been found, and Adonis may be the smallest. The asteroids are not easy to see. One of them, Vesta, should be theoretically visible to the naked eye at times, but it is not easy to find it even though





**An asteroid trail.**

its position may be accurately known. Most of the asteroids have been found by accident or by serendipity. Many of the large observatories have patrol cameras which are automatically taking pictures of various regions of the sky all night on every clear night. On the plates thus secured, from telescopes that are being moved against the motion of the Earth so that the stars will register as clean points of light, there are often found tiny streaks that indicate the presence of objects with a motion of their own and that are near enough so that this motion differs from the apparent motion of the stars, which is caused by the real motion of the Earth. Investigation of these streaks often reveals an asteroid.

The close passage of some of the asteroids to the Earth has helped astronomers revise and refine measurements of the astronomical unit, the mean distance between the Earth and the Sun. When an asteroid is scheduled to be in a certain position in the sky as seen from one place on the Earth's surface, it will appear to be displaced from that position when it is viewed by an observer in a different location on the Earth. This apparent displacement will pinpoint the distance

to the asteroid and, by triangulation, the distance of reference objects, such as the Sun.

The origin of the asteroids is a matter of speculation. There are two favored theories. One is that two small planets, moving in orbits dangerously close to each other, collided, and the debris of that collision is the asteroids. The other and more acceptable theory is that the asteroids are material from which a planet might have been formed except for the disruptive effect of the gravitational field of Jupiter, which kept the material from coalescing into a planet. No one knows exactly how many asteroids there are. The total mass of the material in the asteroid belt can be calculated from the gravitational effect of all the asteroids on the orbits of the neighboring planets. This effect is the same as would be exercised by a body about one one-thousandth of the mass of the Earth. The total number of asteroids, of course, would depend upon the number of particles into which such a mass was broken. Estimates run as high as fifty thousand asteroids, but we shall probably never know when, if ever, the last asteroid has been discovered. This belt of celestial rocks figures large among the hazards of interplanetary travel, and it is likely that some enterprising broker will write insurance against possible collision when, as, and if man plans to penetrate space beyond Mars.

## Comets and Meteors

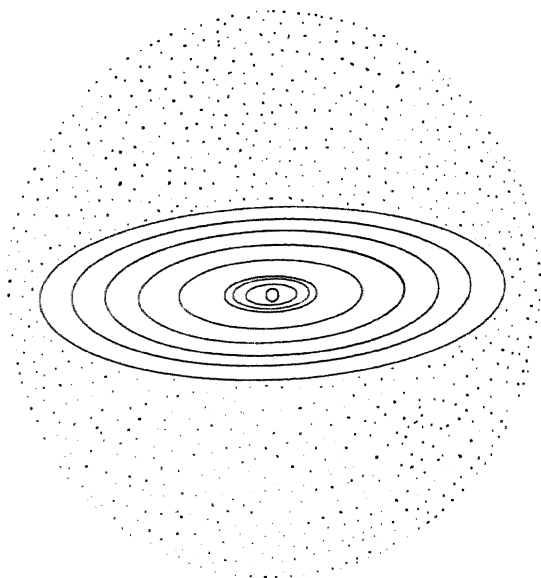
NEXT TO ASTRONOMY, one of the most fascinating hobbies is the dissection of English words. "Disaster," for example, is fabricated from *dis*, the Latin word for "evil," and *astron*, one of the Greek words for "star." During his brief occupation of the Earth, man has ever been on the lookout for natural phenomena upon which he could throw the blame for the evils he had to endure because of his own mismanagement. The stars were excellent scapegoats. "Evil stars"—great flaming apparitions with long tails—appeared in the sky frequently enough to keep man reasonably happy at having an excuse for his own shortcomings. Comets were probably never directly called disasters, but because they appeared with long manes streaming out behind them, they were known as hairy stars. The word "comet" comes from a Greek word that means "long-haired"—*kometes*.

Before telescopes no comet could be seen until it had made its way close enough to the Sun, and consequently close enough to the Earth, to be visible. Its proximity to the Sun and its reaction to the Sun's radiation give a comet its light and its tail. In modern astronomy, comets are more often seen in an intermediate stage, when they have been illuminated but before they have developed tails. In this stage they could never have been known to pretelescopic observers, who first saw a comet when it was a bright, "long-haired"

star. The ancients also never knew of the many comets that never reach naked-eye visibility but that modern methods discover at the rate of about a dozen each year.

Comets were believed to be many things. After man began to use common sense in his interpretation of natural phenomena, comets were considered to be made of debris from terrestrial volcanic eruptions, which was cast into space and floated at random until it approached near enough to Earth to be seen again. Or comets were emanations from outer space, again wandering at random until they came near enough to the Earth to be visible. By the end of the seventeenth century comets had lost much of their evil connotation. Samuel Pepys mentions, with lively curiosity but without undue concern, comets that were visible over London between 1660 and 1669.

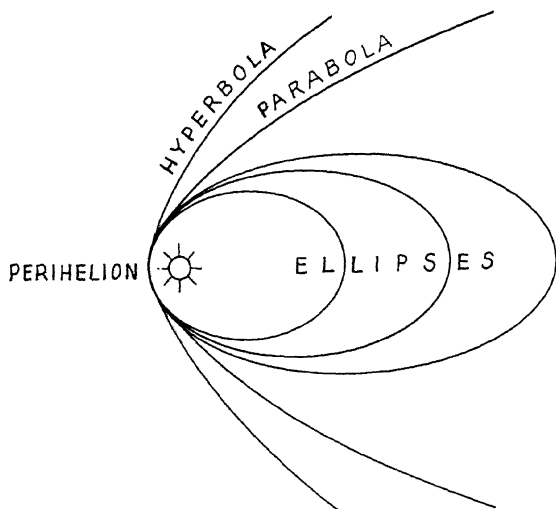
We believe that we know more about comets than did the observers of those days, but we still do not know where the materials of which comets are made originate, or how they come together, or how they get to wherever they come from. We do believe that comets are also captives of the Sun, members of the solar system, but since we do not yet know the origin of anything else in the solar system, comets should hold no more mystery for us than any of the system's other components. The present theory that accounts for the entrance of comets into that part of the solar system in which they can be seen from the Earth, comes from Dr. Jan Oort, a modern Dutch astronomer. Dr. Oort presents the hypothesis that the solar system has a shell of comets that circulate about the Sun generally outside the region occupied by the planets. This layer of comets moves slowly about the Sun, each comet following its own orbit, at a general distance of about 150,000 astronomical units from the Sun. This is about half the distance from the Sun to Alpha Centauri, the nearest star in space. In round figures it comes to about thirteen million million miles. This picture vastly increases the generally



**A haze of comets may form the outer region of the solar system.**

known dimensions of the solar system.

This spherical cloud of comets hovers around the border of the solar system, held in its position by the same force that keeps the other captives of the Sun in place, the gravitational force of the Sun. The comets move through space with the Sun, circling about it in every direction, not in almost the same plane and in the same direction, as do the planets. Now and then one of the comets drifts near enough to one of the distant planets, which are the giants, to be captured by its gravitational force. It is thus drawn away from the comet stream and started on a journey through the solar system and around the Sun. Thereafter, the captive comet is thrown into an orbit that is usually an extremely eccentric ellipse extending from the neighborhood of the Sun outward to a point at about the distance from the Sun of the planet that made the capture. The comet will travel in this orbit until its ultimate destruction by a sort of gravitational erosion by the

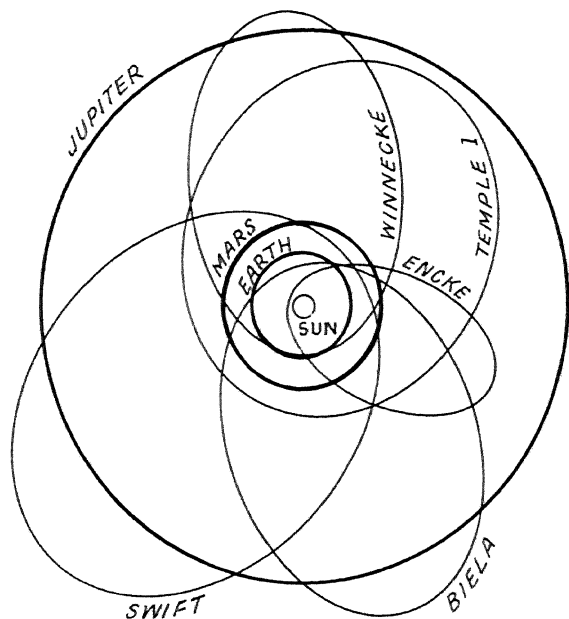


**Various types of cometary orbits.**

Sun, or perhaps by the very planet responsible for its predicament, or until it is banished into deep space by a manifestation of the same force that originally detached it from the comet cloud and launched it on its career.

The velocity at which a comet approaches the Sun is calculated to reach 23 miles a second when the comet has reached the distance of the Earth from the Sun—1 astronomical unit, or 93,000,000 miles. If the comet, coming from a point far outside the solar system, were to meet the Sun coming toward it, its velocity at the distance of 1 astronomical unit from the Sun would be much greater. The average velocity of comets approaching the Sun is just about 23 miles a second by the time the comet has reached a distance of 1 astronomical unit from the Sun. This bit of evidence gives support to Dr. Oort's theory.

Nearer than 1 astronomical unit, a comet could be tremendously accelerated in passing around the Sun. If the course the comet is following brings it too close to the Sun, the comet may be whipped into a parabolic orbit instead of an elliptical one. In such a case, after rounding the Sun, the



**The orbits of several short-period comets.**

comet would shoot off into space and be lost forever to the solar system. This has happened—notably to the Great Comet of 1843, which came so near the Sun that it was snapped into oblivion at a velocity in excess of 300 miles a second.

This probably does not happen often enough to discourage the members of the comet family. About a dozen comets are observed every year. By no means all of these are new ones. Almost half of them have been seen before and are repeaters, following the courses into which they were thrown by their passage near one of the major planets at some previous time. The rest are new, and the fact that there are six or seven new comets each year furnishes a clue to the amount of stock in the cometary refrigerator. To be seen at all from the Earth, a comet would have to approach the Earth to within, at the most, 2 astronomical units, or about 186 million miles. From the region in which the comets circulate, this volume of space represents a tiny bull's-eye; and since the motions of the

comets must be at random, going every which way in their celestial dwelling place, it has been calculated that only one comet in every one hundred million has a chance of hitting this bull's-eye. Because as many as six or seven do register annually on this tiny target, the total number of comets must be at least one hundred thousand million.

The periods of these comets—the length of time required for them to make one journey completely around their orbits—that have been captured by the Sun, can be divided roughly into two groups. There are short-period comets with cycles of return under one hundred years, and long-period comets whose journeys require from one hundred to ten million years. About one quarter of the known comets are short-period travelers, and the rest take the long road. Very few of the new comets that come in each year are spectacular. Modern man seems to be going through a period of deficiency of large startling comets. In the nineteenth century there were six comets that were brilliant and terrifying. So far in this century, we have had only one, and that was an old friend, Halley's Comet. There have been half a dozen that could be seen with the naked eye, but the average man could not have seen these unless an astronomer stood at his elbow, held his head, and directed his glance. In 1957 there were two comets that were technically visible. One, in April, was the Arend-Roland Comet that could be seen in the northwestern sky for a short while after sunset. In August the Mrkos Comet, of about the same brightness, appeared also in the northwest in about the same relative position.

The old, well-known comets follow elliptical orbits, or they would not return time after time. The eccentricities of their orbits are smaller than most cometary orbits, which means that they travel in paths that are more circular than most. The orbits of the long-period comets, however, are of large eccentricity and are tremendously elongated ellipses. The short-period comets also follow orbits that, for the most part, lie near the ecliptic, the path followed by the planets, and a large



number of them move about the Sun in the same direction as the planets. The long-period comets follow paths that go about the Sun at all angles, and the directions they travel are also random—either direct, as the planets go, or retrograde.

The distance from the Sun reached by a comet when it is in that part of its orbit farthest from the Sun determines, to some extent, which of the major planets was responsible for enticing the comet into closer relationship with the central part of the solar system. Comets whose aphelions are at about the mean distance of Jupiter, for example, are said to belong to Jupiter's comet family, and so on. In spite of the vast number of comets postulated by Dr. Oort's theory, they do not contribute much to the amount of material in the solar system. On the average, it would take sixty billion comets to equal the mass of the Earth. Hence, the entire mass of the comet division of the solar system is only about one and a half times the mass of the Earth.

When a comet is out in its natural habitat, it is far from the Sun and is intensely cold with a temperature that must be close to absolute zero, or 459 degrees below zero Fahrenheit. Professor Whipple of Harvard has described a comet, when it is in this region, as a dirty iceberg made of rotten ice. The gases that make up the bulk of a comet, but that contribute very little to its mass, must be literally frozen solid. As the comet approaches the Sun, the Sun's radiation begins to turn this "rotten ice" back into gas and to free the dirt in the "iceberg" from the grip of its frozen state. This dirt is important. Keep it in mind for we shall come back to it later on. As the gas-ice sublimates, the same radiation from the Sun begins to give light to the comet. Some of this light is reflection from the dirt in the comet, and some of it is resonance fluorescence. The radiation excites the gases of the comet; the gases absorb this radiation and produce a secondary radiation of their own that differs slightly in wave length from the Sun's radiation, but makes the comet visible.

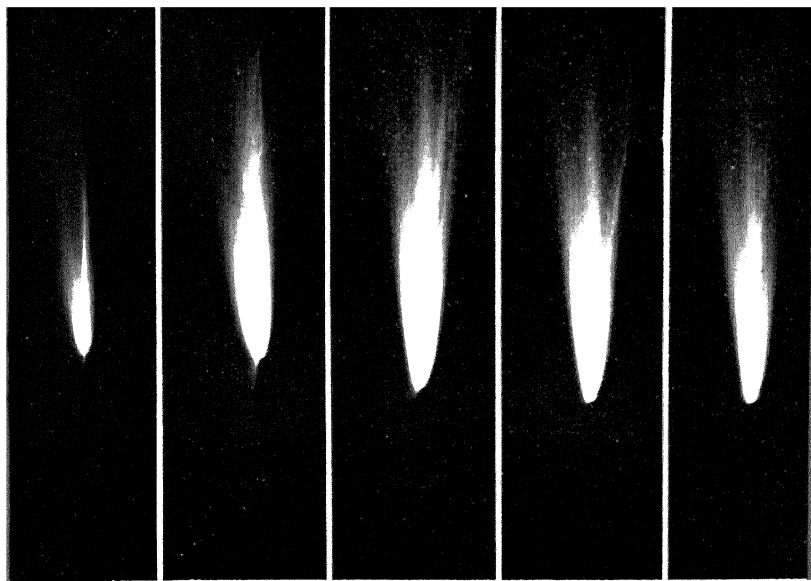
The materials that compose a comet are, in the main, the



**The physical elements of a comet.**

same that are found in the substances we know as ammonia, methane, and water. Out in space the materials are frozen into ice as a solidified form of methane and ammonia. In the frozen mass are the particles that make the comet "dirty," as Whipple puts it. These are bits of material ranging in dimension from microscopic particles to good-sized rocks. The presence of this material makes the sublimation of the comet irregular and may cause unusual appearances as the comet becomes visible. A substantial deposit of this solid material in one place in the comet, for example, may shield the ice below it from radiation for some time, and then suddenly melt loose and permit a jet of released gas to appear. The force behind such concentrated jets of gas may serve to alter the normal course of the comet slightly and even to change the length of its period of travel about the Sun.

The distinguishing feature of a comet is, of course, its tail. The tail is made when the gases in the head of a comet have been vaporized by the Sun. The same forces that turned the solid ices into vapor are strong enough to drive this vapor away from the head of the comet to form its tail. It is for this reason that the tail of a comet will point generally away from the Sun. When a comet is coming in from space toward the Sun, the tail will be in the normal position that one would expect a tail to occupy, trailing behind. When the comet has made its turn about the Sun and is on its way back to outer



April 26

April 27

April 29

April 30

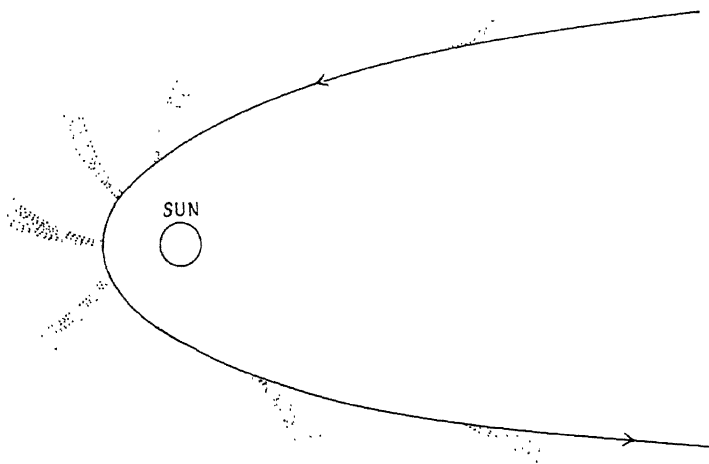
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**Progressive photographs of the Arend-Roland Comet.**

**Note jet formation in first two photographs.**

space again, the tail is pushing ahead of the comet. The direction in which the tail is pointing will be affected somewhat by the course the comet takes in relation to the Sun and by the size of the molecules of gas in the tail. These molecules and other particles all immediately obey Kepler's laws of planetary motion when they leave the head of the comet and begin to move about the Sun on their own. Hence, the tail of a comet may not point directly away from the Sun, but it may assume a slight curve. The tail is, however, always on the side of the comet away from the Sun.

The gases and solid particles that are expelled from the head of the comet by the force of the Sun's radiation are, of course, lost to the comet forever. Every comet is reduced in mass by every passage that it makes about the Sun. The average comet is deprived of about one half of 1 per cent of its material in such an adventure and would, therefore, be



**The effect of solar radiation and light pressure  
on the direction of the tail of a comet.**

able to endure about two hundred voyages about the Sun. In the case of a comet with a short period—the shortest we know of is that of Encke's Comet, which has a period of three and one half years—we can estimate the life of the comet at the time required to make two hundred returns. Encke's Comet, then, would exist for about six hundred years. Some of the larger comets may lose a slightly smaller proportion of their total mass each trip and may survive a greater number of revolutions.

The concentration of frozen gases and solid particles is the head of the comet. When the comet is far from the Sun and is solid, it is all head. When the comet approaches the Sun and radiation begins to erode it, we see a bright nucleus, almost starlike in appearance, which contains the major part of the material of the comet. This nucleus is surrounded by a mist of gas which is called the coma and of which the comet's tail is really an extension. As the comet deteriorates under repeated revolutions about the Sun, the proportion of solid material to gas becomes greater and greater. Some of this solid material is carried out from the head of the comet with

the gases that form the comet's tail, particularly if there happens to be a concentration of such material which might be suddenly freed by melting. The solid particles at first remain in a clump, but this clump will gradually be broken up and distributed along the orbit of the comet as it moves about the Sun. This scattering of the particles from the clump is caused by the gravitational forces of the Sun or of one of the planets as the particles revolve in the comet's orbit.

The size of a comet varies tremendously during its career. When a comet is distant from the Sun and is frozen, its material is, of course, concentrated in the smallest possible volume. For the average comet, this volume has been calculated to be a sphere with a radius of slightly more than half a mile. There are exceptions on both sides of this dimension, as there are in all average cases. As the gases sublime, the volume of the comet increases tremendously, while its mass remains the same or even decreases from the erosive effects of the Sun. There have been comets that, when visible, had radii almost as large as the radius of the Sun, and most of them are at such times larger than the Earth. With an average mass of one sixty-billionth of the mass of the Earth, the density of a comet when it is nearest the Sun must be next to nothing at all. Percival Lowell called comets "bags full of nothing." When Halley's Comet appeared in 1910, it passed directly between the Earth and the Sun and was completely invisible during that passage. The total lack of interference with the light of the Sun by the comet at that time testified to the scantiness of the comet. It cast no shadow whatever.

The tails of comets are even more unstable than the rest of the comet. The appearance of a comet's tail changes constantly, sometimes in a few hours. It will be even and uniform, for example, for most of a night, and then a bright burst will appear, originating in the head of the comet and traveling out through the tail. This fairly common form of change is probably caused by the release of light gases that had been



**The head of Halley's Comet.**

shielded from radiation by a crust of inert solid particles until that crust suddenly melted and freed the gases below it. The extent of a comet's tail depends upon the amount of material available to be converted into gas and the distance of the comet from the Sun. When comets are first seen, provided they are discovered at some distance from the Sun, little or no tail may be apparent. As a comet nears the Sun, the tail grows in brilliance and in size. A giant like Halley's Comet may have a tail many millions of miles in length at its greatest development. The tail of Halley's Comet in 1910 covered an arc of about 120 degrees, or two thirds of the distance from one horizon to the other. By contrast, the tails of some of the smaller and perhaps older comets have been almost non-existent.



**Old drawing of DeCheseaux's Comet, March, 1744.**

Because of the extreme tenuity of the material of which the tails of comets are made, some unusual formations have been observed in these airy appendages. Comets have been seen to break up into two or more pieces under the debilitating influence of the Sun; once the various fragments have become definitely separated, provided they are substantial enough, each may develop its own tail. A comet that appeared briefly in southern skies in 1946 broke in two shortly after its discovery and flaunted two tails for a few nights until it was evidently destroyed. One famous comet that appeared in the late years of the eighteenth century produced no less than seven tails. This was DeCheseaux's Comet, which contemporary drawings show at the eastern horizon with its tails fanned out across the sky.

Comets are named unofficially for their discoverers. The notable exception to this rule is Halley's Comet. Its discoverer is completely unknown, for the earliest report of a great comet that was almost certainly the one later known as Halley's dates back to 240 B.C. A calculation of its probable returns has been made and checked against ancient and medieval records and manuscripts. Its career has thus been traced back to 87 B.C. at least, and perhaps to the earlier date. A hyphenated name given to a comet may mean that the comet was discovered by a partnership of observers, as in the

case of the Arend-Roland Comet of 1957. The hyphen may also mean that the original discoverer and the observer who first saw the comet on its first return have both been given credit.

Officially a new comet is given a designation that is made up of the year of its discovery followed by a small letter whose position in the alphabet signifies the order of its discovery among the comets of that year. Comet 1959b, for example, is the second comet discovered in 1959. After discovery the comet is carefully observed, and its orbit is plotted in order to determine whether the comet is actually a newcomer or whether it is an old stager returning on another trip. If it is found to be a new comet, it is given another designation made up again of the number of the year followed by a Roman numeral which indicates the order of its perihelion passage among the comets recorded during that year. Comet 1959b might eventually become Comet 1959II, or it might have a different Roman numeral depending upon its place among the comets of 1959 in passing closest to the Sun. At least three different observations of a comet are needed to determine its orbit exactly. Since there are no visual distinguishing features about a comet, it is the orbit alone that identifies it and tells us whether it is a new comet or an old-timer.

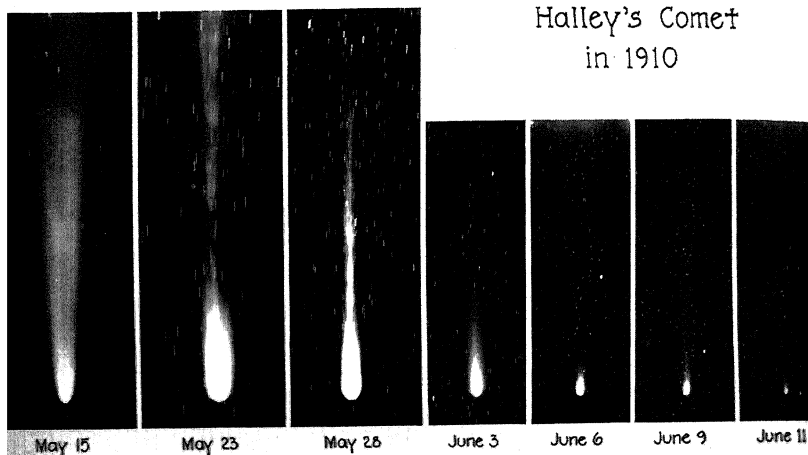
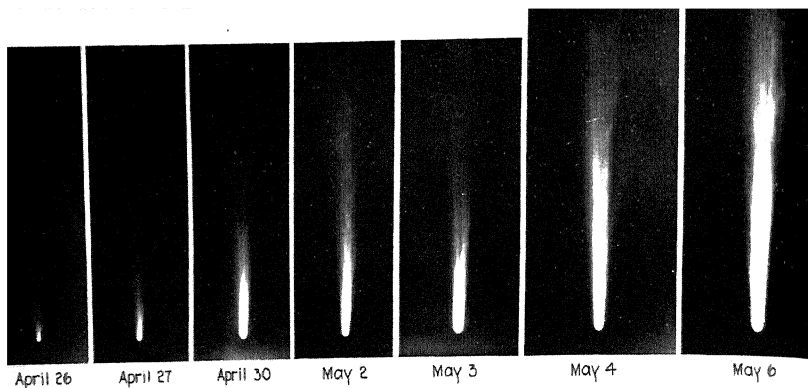
The naming of Halley's Comet is, as has been said, an exception to the general rule. Edmund Halley was born in 1659 and became the second British Astronomer Royal, succeeding John Flamsteed in 1720. In 1680 and again in 1682, bright comets appeared and aroused Halley's interest in this particular type of celestial object. He began an investigation of comets and listed all that he could find any record of, together with their elements and with all other data about them; and he had a fairly complete catalogue of comets from 1337 to 1698 when he had finished. As he made his list, he noticed that a bright comet had appeared fairly regularly at intervals of about seventy-six years, notably in 1531 and in



1607. He felt that this was the same comet and that it had appeared on these two occasions and again in 1682. This made him believe that it, and consequently all comets, were members of the solar system and not chance visitors from space, as they were then thought to be. Halley tried to calculate the orbit of this bright comet, including all the perturbations to which it might be subject from the Sun and the major planets, but the intricacies of the problem floored him. He turned to his friend Isaac Newton for help. Newton, using the laws of planetary motion that had been formulated about seventy years before by Johannes Kepler, confirmed Halley's opinion. Halley then stated that the bright comet would appear again in 1757. Halley asked that, if it did, it be remembered that an English scientist had predicted its return. Halley died in 1742. And the comet did appear, although it did not pass through until March 1759. Its delay was accounted for by the attraction upon it of both Jupiter and Saturn, as it passed relatively near these planets, and it was at once named for the man who demonstrated that comets, too, were captives of the Sun.

There have been twenty-eight recorded visits of Halley's Comet since 240 B.C. It is the only really bright comet whose period is less than one hundred years. Halley's Comet was in the skies at the time of the Norman invasion of England, and it is shown on the Bayeux tapestries, which are a woven record of that campaign. Some individuals in the costume of the period are watching it under the legend "*Iste mirant Stella.*"

It is not possible to predict the precise date and time of the return of Halley's Comet or of any other comet, because of possible perturbations caused by the larger planets and by the Sun itself. Over the years, however, the average time between perihelion passages of Halley's Comet is seventy-seven years. It was last visible in April and May 1910, so it may be expected again in 1986 or 1987.



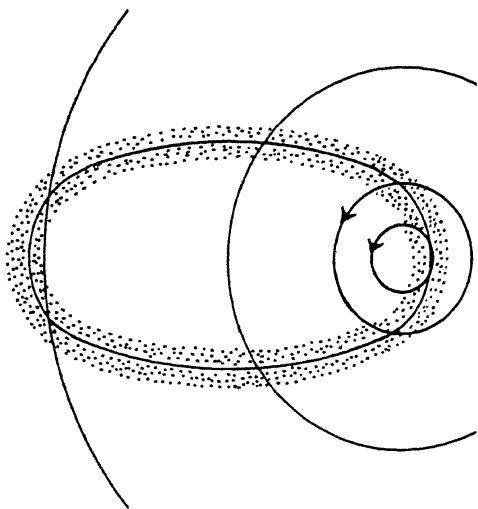
## Halley's Comet in 1910

**Series of photographs showing development of  
Halley's Comet in April, May, and June, 1910.**

Comets are discovered now, for the most part, through the examination of photographic plates that have been exposed as a matter of routine by patrol cameras that are operated almost automatically every clear night by the larger active observatories. Comets may also be discovered on plates taken specifically for other purposes. A search for comets that may be so close to the Sun that they could not be easily seen is made during every total eclipse of the Sun, when the darkness caused by the Moon's passage before the Sun makes possible

the exploration of the sky near the Sun. Comets are also discovered by amateur observers who set up small telescopes nightly for the observation of variable stars or for the sheer joy of exploring the skies. Some observers make systematic comet searches, studying carefully the western sky as soon as possible after sunset or the eastern sky as long as they can before the approaching sunrise washes out the night. One variable star observer has become famous through the discovery of about a dozen comets during his long and valuable career. Since comets are most likely to be visible when they are near the Sun, the vicinity of the Sun is the most fruitful region for their discovery.

The appearance of a comet, particularly if it is bright and spectacular, is always a cause for fearful speculation on the part of its observers. What if it should strike the Earth? Such fears are natural, but they appear to be groundless. There is no evidence that the nucleus of a comet has ever struck the Earth, and the chances of such an encounter are about one in a billion. First, a comet, in order to register a hit upon our tiny planet, would have to pass nearer to the Sun than 1 astronomical unit. Each comet has two chances of doing this provided its orbit permits such a close passage. It may come as close as this once on its way in from the outer reaches of the solar system and again on its way out after it has passed around the Sun. There are on the average about five comets each year that do come sufficiently close to pass nearer the Sun than the orbit of the Earth; so, with the chances being what they are, the danger of the Earth's being struck is reduced to the possibility of one collision every 200 million years. If such a meeting should occur, the amount of damage would depend upon the amount of solid material in the comet. The collision could cause a local catastrophe that might demolish a large city, or it could result in nothing more than a minor scattering of meteorites.



**The Earth passes through several meteor swarms each year.**

#### METEORS

We do receive the benefits, if that is the word, of the passage of a comet near the Earth in the displays made by the solid particles that the comet leaves behind it along its orbit. When the Earth, in its journey about the Sun, crosses the orbit of a comet, it encounters these particles. The effect of such an encounter is seen from the Earth when these particles plunge into the Earth's atmosphere, are heated to incandescence by friction, and burn up. These burnings which result in swift streaks of light, apparently among the stars, are meteors, often called shooting or falling stars.

Eight thousand million times every day the atmosphere of the Earth is penetrated by a solid particle—a pellet from space. Fortunately for us who live upon the target, the average size of these particles is less than that of a grain of sand. Of all this numerous collection of bits and pieces from space, only about two thousand each year survive their trip through the atmosphere and reach the Earth's surface. The average

mass of such survivors is about 50 pounds, and because of the high density of meteoric material, such a sample would be about the size of two ordinary building bricks. The United States gets about twenty-five of these annually. The entire accumulation adds about fifty tons every year to the mass of the Earth. In addition to the increase from those that land in recognizable units, there is enough dust and ash left over from those that are destroyed by the heat of the friction from their swift passage through the atmosphere to increase the mass of the Earth by about 2,000,000 tons annually; this dust and ash which seeps slowly down through the atmosphere is found everywhere: on top of the highest mountain peaks or in the ooze at the bottom of the great ocean deeps.

The largest single chunk of this celestial artillery to reach the Earth—judging by what is left of it after its debilitating trip through the atmosphere—lies buried to within a few inches of its upper surface near Grootfontein in South West Africa. It is estimated to weigh nearly 50 tons. This is the Hoba West Meteorite.

It is hardly possible for anyone to remain out-of-doors for very long on a clear night without seeing one or more of these

**The Hoba West Meteorite, near Grootfontein,  
South West Africa.**



minor captives of the Sun on their way in toward Earth. The figures in the paragraph above indicate how few of those that reach the atmosphere succeed in completing the trip to the Earth itself—about one in four million. What the observer sees of a very few of these four million daily arrivals is a swift, short streak of light lasting for one or two seconds as a rule, apparently coursing across the sky among the stars. A fine resounding body of legend has been built up around these so-called shooting stars. They have been called the passages of souls to heaven; leprechauns on their way from one bit of mischief to the next, or angels on errands of mercy. They are, of course, none of these, nor are they stars. The stars among which they seem to pass are infinitely farther away. A meteor is usually from 20 to 60 miles away when it is seen. A meteor, incidentally, is what you see—the visible manifestation. The tiny, solid body that strikes the atmosphere is a meteoroid. A meteoroid that has reached the Earth is a meteorite. The word "meteor" is of Greek ancestry and means "something in the air"; the meteoroid is the object that causes something in the air. It is somewhat confusing that the science concerned with weather is called meteorology, although this is a most logical term for it.

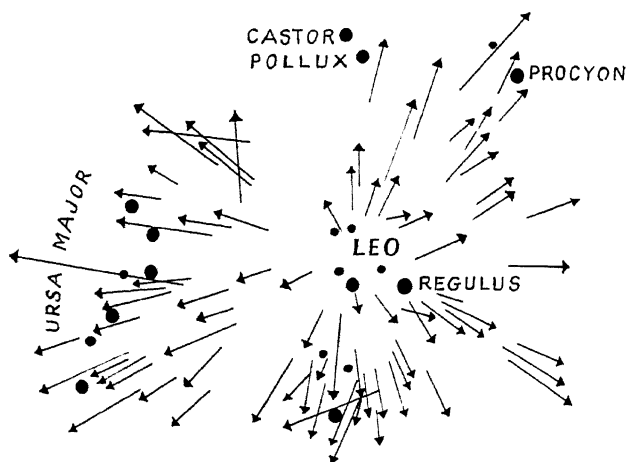
Meteoroids are captives of the Sun. We have spoken of them in connection with comets, and it is perhaps possible to justify the theory that comets are ultimately responsible for all meteoroids. We know that much of the mass of a comet is this solid material that is embedded in the frozen gases that make up the comet when it is far from the Sun. These solid particles are released by the vaporization of these gases when the comet approaches the Sun, and are lost to the comet in large numbers each time that it sweeps around the Sun. The average comet is completely disintegrated after it has made 200 trips around its orbit, and all of its store of solid particles has been let loose in space, at first following the orbit of the comet. Gradually the gravitational effects of other

bodies near the path of the comet, and consequently, near the path that these particles are following, disperses and scatters them lineally along the cometary orbit and spreads them out laterally as well, until the integrity of the original meteoroid stream is destroyed and the meteoroids are fairly evenly scattered in space among the planets.

When this random distribution has been accomplished, the Earth is likely to encounter meteoroids at any time. Such evenly and casually distributed particles form the large class of sporadic meteors. Those meteoroids that still remain in cometary orbits so that the Earth runs into them only when its journey around the Sun carries it across the orbit of the comet from which they originated, make a concentrated display at the times of such encounters and are called shower meteors and the concentrated display they cause are meteor showers.

There are fourteen meteor showers recognized by the Royal Astronomical Society which occur every year regularly on the same date. These showers are, however, exceedingly variable as far as their appearance is concerned. Some of them are spectacular one year and negligible the next in the number of meteors they produce. Eight of these showers are definitely associated with known comets. If the other showers were produced by comets, the association can no longer be proved.

The meteors in a shower appear to radiate from one general location in the celestial sphere. Although the trails left by the meteors are parallel, perspective gives them a vanishing point from which they all seem to radiate; this vanishing point is called the radiant. Since showers occur regularly at the same time each year, the radiant is relatively fixed as to the stars beyond it and appears to lie in line with a particular location, such as a constellation or even an individual star. Meteor showers are named according to the location of their radiants. The recognized meteor showers are



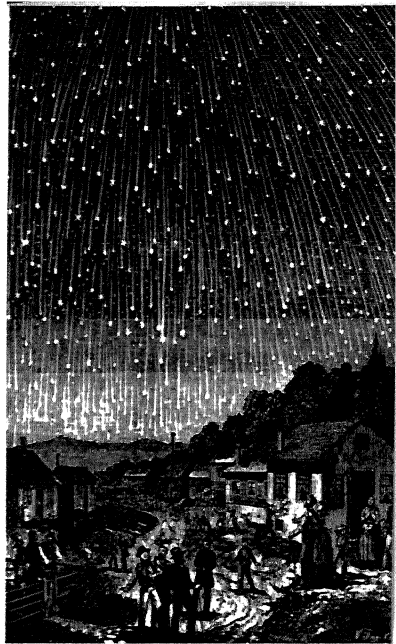
**Meteors of the Leonid meteor shower showing the shower's radiant.**

listed here, with their dates. Those that are associated with known comets have the names of those comets included in the listing. The hourly rate of meteors that may be seen by a single observer is also given.

| <i>Shower</i>  | <i>Date</i> | <i>Comet</i> | <i>Rate</i> |
|----------------|-------------|--------------|-------------|
| Quadrantids    | January 3   |              | 35          |
| Aurigids       | February 9  |              | 12          |
| Lyrids         | April 21    | 1861 II      | 12          |
| Eta Aquarids   | May 4       | Halley       | 20          |
| Draconids      | June 28     |              | 12          |
| Delta Aquarids | July 29     |              | 20          |
| Perseids       | August 11   | 1862 II      | 50          |
| Draconids      | October 9   | 1933 III     | 12          |
| Orionids       | October 20  | Halley       | 25          |
| Taurids        | November 5  | Encke        | 15          |
| Arietids       | November 12 |              | 12          |
| Leonids        | November 16 | 1866 I       | 20          |
| Geminids       | December 13 |              | 40          |
| Andromedids    | November 27 | Biela        | 12          |

Two of these showers are associated with Halley's Comet: the Eta Aquarids in May and the Orionids in October. They probably come from the scattered stream of particles left by





**The great meteor shower of 1833.**

the comet first on its way in toward the Sun and again after it had passed around the Sun and was on its way back to the outer reaches of the solar system.

The classic example of the association of a meteor shower with a comet began in 1833 when the night of November 12 was made memorable by the greatest recorded meteor display. The meteors appeared at the rate of about 200,000 an hour, and they all seemed to come from one point in the sky. The shower of 1833 was apparently centered on a point between the Earth and the stars of the constellation of Leo, which, of course, are infinitely more distant than the meteors and have nothing whatever to do with them. This shower was called, therefore, the Leonid Shower. A similar display, somewhat less concentrated, had appeared in 1799, and there was another less exuberant fall in 1866. This coincidence of dating gave rise to the theory that the meteor swarm was in such a position in space that the Earth would encounter it every 33 years. A search of old records showed that annual meteor activity had occurred on this date at such intervals since A.D.

902, and in 1866 a faint comet was seen whose orbit coincided with the orbit of the meteors.

After 1866, however, something happened. The stream of meteors that had probably been torn from the comet by melting and by the gravitational forces of the Sun was diverted by its passage close to Jupiter. The course of the meteors was so changed that their orbit was removed from the path of the Earth, and we now get only the outer fringes of the concentration through which we used to plunge every 33 years. The comet that caused the shower has disappeared, probably disintegrated completely by the Sun. This may be the long-range pattern of the distribution of meteors. The comet and its meteors travel in the same orbit for a time, with the comet, of course, in one definite spot but with the meteors increasingly distributed along the entire orbit as the years go on. Finally, the comet will disappear as a comet, but its legacy of meteors will still be scattered along a path in space. The gradual encounter of these meteors either directly with a planet or the disturbance of the stream by the forces of gravity of the planets serves to distribute the meteors more and more widely along the former orbit of the comet and, at last, to scatter them at random in space.

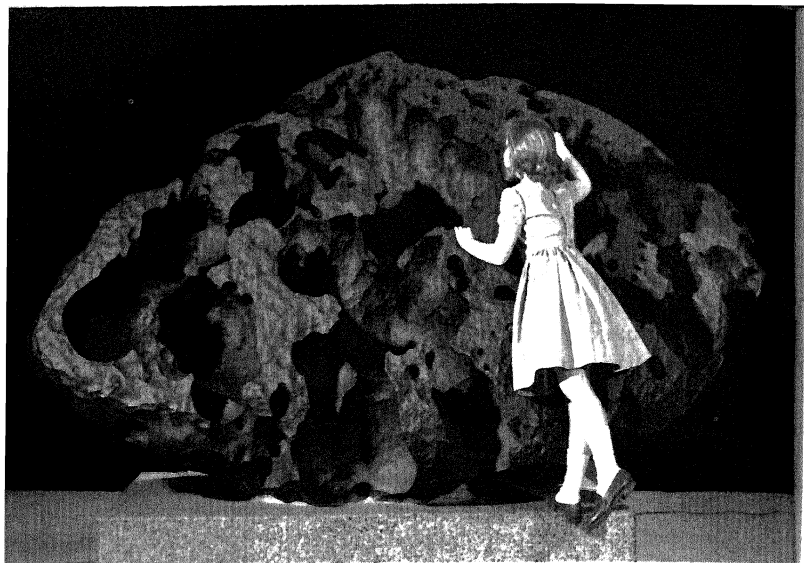
The meteor showers in the list that are not definitely assigned to known comets may be the debris of prehistoric comets which disintegrated ages ago, but whose meteoroids have not yet been thoroughly distributed through the solar system. The sporadic meteors may come from comets even older.

If a meteoroid were to come from far out in space, from the region of the stars rather than from among the planets, it could be recognized by its tremendous velocity which would have to be greater than 25 miles a second. If the Earth were to meet such a meteoroid, its own velocity of 18.5 miles a second would be added to the velocity of the meteoroid so that the two would meet at almost 45 miles a second. If such a far-traveled meteoroid overtook the Earth

instead of meeting it head on, the resulting speed of the encounter would be the difference between the two velocities, or about 7.5 miles a second. If, then, we can record a velocity of 45 miles a second head on or 7.5 miles a second overtaking, we know that we have met an interstellar meteoroid. Up to this moment no such visitors have been recorded. As far as we know, every meteoroid or meteorite that has either entered the atmosphere or reached the Earth is and always has been a captive of the Sun—a member of the solar system.

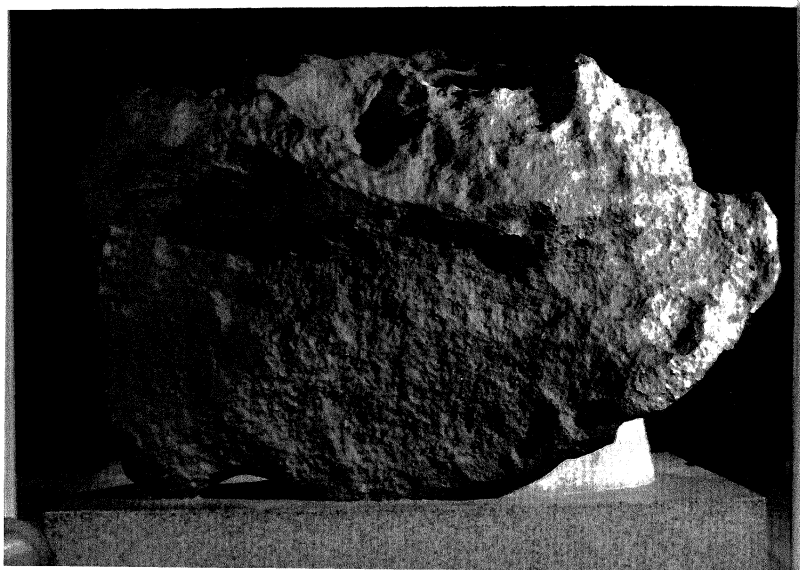
It is safe to assume that every meteor is caused by the same sort of object, except for size, as those that have landed upon the Earth and that we have therefore been able to examine. These meteorites are divided into two general types: those made of stone and those made of metal. The metal meteorites are easiest to identify because they are composed of nickel-iron in a form that does not exist on Earth. The stony meteorites are much like terrestrial rocks of the igneous type and have in them many of the same materials. Their identification is much more difficult than is the identification of metallic meteorites, but there is always a trace of iron even in the stony meteorites, which is not the case with terrestrial rocks. Of the thousands of specimens that have been brought into one planetarium for identification over the years, not one has turned out to be a meteorite in spite of a long procession of witnessed falls. Apparently these things take wing after they hit the Earth, and go somewhere else, leaving a harmless rock to be nabbed on circumstantial evidence.

This is not to say that meteorites have not fallen. On the contrary, in addition to certain examples such as the Hoba West Meteorite in Africa, there are many authentic meteorites in existence. The largest ever found in the United States is in the American Museum-Hayden Planetarium in New York City. This is the Willamette Meteorite, named from the location in which it fell, probably thousands of years ago, in the Willamette River Valley in Oregon. One side of this metallic meteorite is deeply pitted with roughly round de-



**The Willamette Meteorite, showing eroded surface.**

**The Ahnighito Meteorite in the American Museum-  
Hayden Planetarium in New York City.**



pressions of various sizes, while the other side is relatively smooth. The pitted side is the one that was exposed for many years to the weather of the region in which the meteorite lay half buried. The corrosive action of the Earth's atmosphere ate out much of the ferrous material: the meteorite literally rusted away. It endured much more destructive treatment after it landed than it did during its flight.

In the same planetarium is the largest meteorite that was ever removed from its original landing place. This is the Ahnighito Meteorite, which was found in the Cape York region of Greenland by Admiral Robert E. Peary and was brought by him to the United States early in this century. It was called the Tent by the Eskimos and was christened Ahnighito by Admiral Peary's daughter just before it was loaded on the ship that was to bring it south. Ahnighito was the name of the Eskimo nurse who cared for Peary's daughter in Greenland. The Ahnighito weighs 34 tons 85 pounds. This was determined a few years ago when the Toledo Scale Company built a special scale and assembled it under the meteorite, which was hung in a tremendous tackle during the operation. Before that, the weight of the meteorite had been estimated at anywhere from 36 to 60 tons.

The Eskimos spoke of this meteorite as the "iron stone" and had chipped away chunks of it, from which they fabricated knives and fishhooks before the white men brought them better and easier-made tools. The Ahnighito was one of a group of meteorites that evidently fell at the same time. A smaller meteorite, of about 3 tons and called the Woman, is also in the American Museum-Hayden Planetarium.

It is evident that the impact of a body as large as any of these would cause some destruction to the Earth. There have been two notable falls in historic times, both of them in Russia. In June 1908 a tremendous meteorite or group of meteorites fell in a desolate region of Siberia. This fall was witnessed by people who were far enough from it to escape

injury, but they saw the fiery plunge from the sky, heard the thunder of its progress, and felt the shock of impact, which registered on several seismographs. It fell in a forest, and over an area about the size of the state of Delaware, the trees were blown down in a pattern radiating outward in all directions from the point of impact. On February 13, 1947, another meteorite struck in a mountainous region of eastern Siberia. This one was seen, too, as a blinding ball of light followed by a black trail of vapor. More than one hundred craters were found where the object had fallen, scattered over an area of almost 3 square miles, and, again, trees were leveled and scorched far around.

In the United States there is a crater that is believed to have been formed by a meteorite fall. This crater is called, variously, the Barringer Crater, Coon Butte, Canyon Diabolo, and Meteor Crater. It is in Arizona near the town of Winslow. The hole is roughly circular, about 600 feet deep, and almost a mile in diameter. Many fragments of meteoric material have been found around the rim of the crater, and it is believed that the main mass of the meteorite may be buried deep beneath the south wall of the crater. It is also possible that there may not be any large pieces remaining at all. When an object of the mass of one of these large meteorites has its forward progress suddenly stopped, as it would when it struck the Earth, the energy due to mass and motion is instantly transformed into heat, and the meteorite explodes like a bomb. Any large mass would be reduced to small fragments, and the explosion could gorge out a much larger hole than could be accounted for by the actual diameter of the meteorite if it fell intact. It is much the same process that occurs when an artillery shell explodes. A 6-inch shell can produce much more damage because of its explosive qualities than it could if it were solid.

The volume of a meteorite that could produce a hole like Meteor Crater must have been about 10 cubic yards, and its

mass about half a million tons. The Earth has undoubtedly been struck by such missiles many thousands of times during its existence. The absence of the scars of such encounters must be attributed to the erosive effect of the Earth's atmosphere. If rain, snow, frost, and wind can, in time, reduce the most massive and towering mountain ranges to mere foothills, these same forces would make relatively short work of the scars left by the greatest of meteorites. Such old wounds as Meteor Crater are still in existence because they are either recent or in a part of the country whose fairly dry and even weather has had little effect upon them.

It is probable that the incidence of large meteorites was much greater during the early period of the formation of the solar system than it is now. Many of these large missiles have been swept out of space or are locked up in distant comets. The Earth may have been struck millions of times by gigantic meteorites during the period when its crust was hardening and soon after, but various erosive influences have erased the marks of these early encounters. This would not be the case with the Moon, which is, to all intents, in the same part of space as the Earth and which would have been struck almost as often, considering its smaller size and weaker gravitational attraction. The Moon, however, has no atmosphere to erase the scars of this prehistoric bombardment. Many astronomers hold that many of the Moon's craters and, indeed, its maria were formed by tremendous meteorites that struck and burst and were even vaporized by the heat of impact, melting themselves and the surface material of the Moon where they struck. This conglomerate cooled and flowed smoothly to make the great, flat, dark areas that are so prominent on the Moon.

It does not take much of a meteoroid to make a startling shooting star. A particle about the size of a pinhead will produce an easily seen trail of bright light. When a meteoroid enters the atmosphere with a velocity that may be as high as 45 miles a second if it comes from the direction in which the

Earth is heading, its friction with the molecules of air it encounters will soon heat it to incandescence. During its passage it is pushing ahead of it a cushion of air which is moving as rapidly, in relation to the rest of the air through which it is passing, as is the meteoroid and which is heated by the same friction. Both the meteoroid and the cushion of air glow brightly, and since the air cushion is of much greater volume than the meteoroid, most of the light we see comes from it. If the meteoroid is sufficiently large, its surface will become hot while the interior material is still cold; this melted surface material will flow back along the meteoroid and be sloughed off, sometimes leaving a train of sparks which remains visible for some seconds after the meteoroid has passed. Meteorites often show the effects of this melting and flow on their surfaces after they have reached the surface of the Earth and have cooled.

The observation of meteors is part of the science of astronomy. Much of this work is done by semiprofessional teams who record the time, direction, point of first sighting and disappearance, brightness, and duration of visibility of meteors. A meteor-watch team is usually composed of half a dozen watchers and a few recorders who keep the time and set down the data called out to them by the observers, who should be lying on their backs like the spokes of a wheel, facing outward so as to cover as much of the sky as possible.

The photographic observation of meteors has also been practiced for many years. Cameras with a wide angle of view are kept in action automatically every clear night. The positions of these cameras are correlated, so that the angle at which each of them faces the same part of the sky is known. When a meteor appears on a photographic plate, the time of its appearance is a part of its picture. A revolving shutter within the camera spins at a known speed and interrupts the trail that the swiftly moving meteor will leave on the fixed photographic negative. The distance between breaks in this trail caused by the shutter will give the velocity of the me-



teor, provided the same meteor is caught by two different cameras. When this happens, the speed of the meteor, its distance above the Earth, and the length of its travel in an incandescent state can easily be calculated.

For the last few years radar has also been used to track meteors. In the ionosphere, the layer of atmosphere above 100 miles from the surface of the Earth, there are regions that are relatively calm and that do not seem to be affected by the bombardment of particles from the Sun—a bombardment that causes so much disturbance in other parts of the ionosphere. Meteoroids entering the atmosphere ionize the tenuous gases of this part of the atmosphere and can be detected by radar echoes from this ionization at any time, day or night. It is chiefly through the radar detection of meteors that we have been able to determine the velocities of enough meteors to assure us that few, if any of them, were visitors from outside the solar system. Only recently has this same ionization technique been used in a delicate communications process in which a transmitter makes use of the disturbance created by the passage of meteoroids to echo a message to points far beyond the normal range of his apparatus.

Some of the dust on the surface of the Moon may come from the constant rain of meteorites, but much of it is probably the surface material of the Moon itself, churned up and combined with the fragments and shattered remains of meteorites that were originally tremendous objects when they struck the Moon. The explosion resulting from a meteorite's striking the Moon smashes the meteorite into tiny fragments and grinds the surface material where it strikes into dust as fine as flour.

This same powdering process undoubtedly happens when an asteroid collides with a meteoroid. The asteroid, however, cannot hold the resulting dust upon its surface because of its lack of gravitational authority. The dust is scattered into space, and the individual particles, even though they are microscopic, assume their own orbits around the Sun.

## Time

TIME is amazingly complex and difficult to define. A good dictionary devotes almost a column of closely set type to the definition of time in all of its ramifications, beginning with this over-all meaning: "The general idea, relation or fact of continuous or successive existence; infinite duration or its measure." If we can succeed in putting forth the "general idea," we shall have accomplished our purpose.

There is an imaginary line that begins at the northern horizon of wherever you may be, arches through the sky over your head, and continues until it reaches the southern horizon. This line is the meridian. It divides the sky neatly into halves, one to your east and the other to your west. Although you cannot see it, this same line continues on around the Earth below your horizon, beneath your feet, making one great continuous circle around you. The point on the meridian directly above your head is the zenith. The corresponding point beneath your feet on the other side of the Earth is the nadir.

If two people are standing exactly north and south of each other, they will share the same meridian, but each will have his own separate zenith and nadir. If two people are standing side by side, facing north or south, each will have his own meridian, zenith, and nadir.

As the Earth turns on its axis from west to east, it rotates

under every object in space by the time it has made one complete turn. For convenience's sake man has named the period of time required by the Earth to make one complete rotation a day. Conventionally, a day is also the name for the period of time during which a given half of the Earth is in sunlight, and night is the time during which a given half of the Earth is in darkness. In a broader sense, however, the word "day" means the complete light-dark period.

This ceaseless turning of the Earth upon its axis makes everything in the sky appear to move in a direction contrary to that of the Earth's rotation. The Sun, the Moon, the planets, the stars, and everything else in the sky look as though they were moving from east to west. In the beginning of man's observation of the skies, he assumed that what appeared to be the case was actually happening: that all the heavenly bodies did move from east to west about the motionless central Earth. Now the reverse is known to be true. The Earth rotates before the Sun and the stars, making them seem—and only seem—to move. The Earth in its rotation lowers the eastern horizon and uncovers the Sun in the morning. At night the western horizon rises and gradually hides the Sun. To all appearances, the Earth is doing all the moving.

Actually, of course, the Sun and all the other stars and objects in the skies are moving. Let us, however, forget this for a while and consider that, for the purposes of this discussion, everything except the Earth is standing still.

If, then, you remain on one place on the Earth, the spinning of the Earth will make the Sun appear to move across your meridian—this imaginary north-overhead-south line. The instant that the Sun crosses the meridian is called noon. To be safe, let us add a few modifying adjectives and call this instant *apparent local solar noon*.

That means that when the Sun seems to cross your meridian it is noon to you. It is not noon, however, to anyone either to the east or to the west of you, for when the Sun

crosses your meridian, it has already crossed the meridian of anyone to your east and it has not yet reached the meridian of someone to your west. Noon, then, or any other specific point of time, moves around the Earth with the Sun. Actually, noon can only occur simultaneously at places that have the same meridian or the same longitude and are directly north or south of each other.

This makes for an extremely awkward situation. Every community, from east to west, could have its own individual time, differing from the time of its neighbor cities by anything from a few minutes to many hours, depending upon the east-west distance between them. In the provincial pride of the cities, this was the case until 1885. Each community kept jealously to its own individual time, and railroad timetables were marvels of incomprehensible ingenuity.

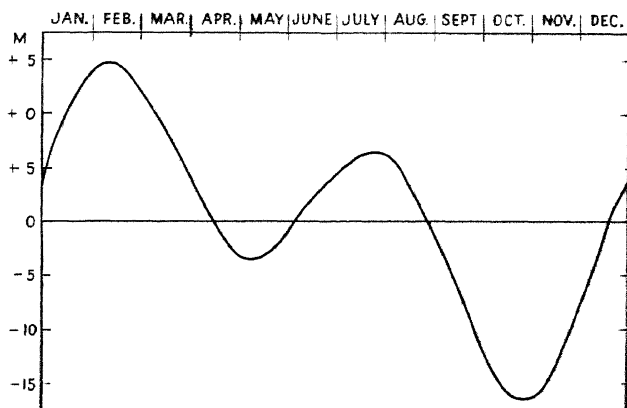
The Earth has two unfortunate qualities of motion and position that make it a poor timekeeper. It moves about the Sun not in a circle but in an ellipse. Because of this eccentricity, or departure from the circular, the Earth moves faster along its orbit in January, when it is closest to the Sun, at perihelion, than it does in July, when it is farthest from the Sun, at aphelion. The Earth is also tilted away from a vertical to the plane of its orbit, so that the Sun does not appear to move around the Earth above the equator, but seems instead to move along the ecliptic, a great circle tilted at an angle of  $23\frac{1}{2}$  degrees to the equator.

These two peculiarities cause the Sun to appear to move erratically, sometimes faster and sometimes slower, through the year. In January, when the Earth is nearest the Sun, the Sun's apparent motion is so rapid that it reaches the meridian about 16 minutes earlier than it does in July, when it is farthest from the Sun and traveling more slowly. Because of the Earth's inclination, the apparent course of the real Sun about the Earth is not even. In June and in December the apparent daily motion of the Sun is, for a short while,

parallel to the equator, although its path is north of the equator in June and south of it in December. The time for its passage along a given distance is the same as though it were above the equator. In March and in September, however, the Sun appears to approach and to cross the equator. Because of the angle of this approach, the Sun takes slightly longer to move through the same east-west distance than does a point on the equator.

To counteract these irregularities, man has imagined a perfectly stable and evenly moving Sun that travels around the Earth above the equator. This is the mean Sun, and the time it keeps is mean time. If you have a sundial, the time it shows is apparent local solar time, and, as you have probably discovered, apparent local solar time and mean time do not often agree. The difference between apparent local solar time and mean time is called the equation of time. The figure for the equation of time must be added to or subtracted from apparent local solar time to obtain mean civil time. This is usually done by using a fixed relationship—mean minus apparent—and adding the difference to apparent solar time, with a change of sign from plus to minus or the reverse where indicated.

#### Graphic representation of the equation of time.

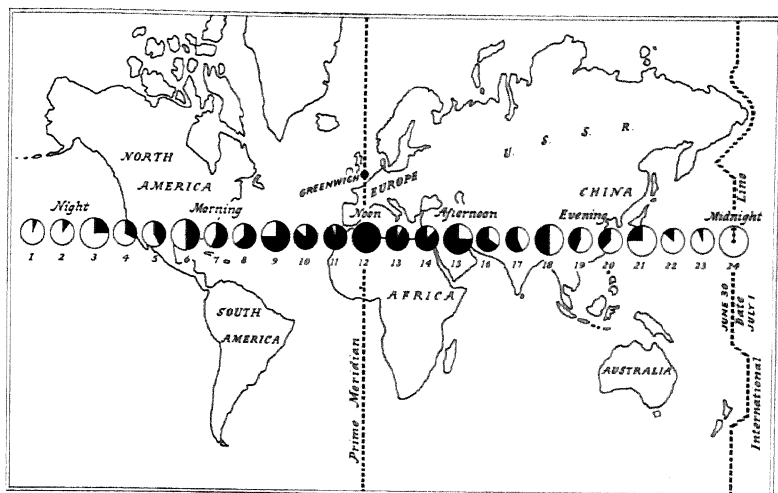


Under the present system of civil timekeeping, the speed at which the Earth rotates is used as the foundation for time regulation. There are 360 degrees in the circumference of the Earth. Since the Earth completes one rotation in one day and since man has divided the day into twenty-four hours, the surface of the Earth turns through 15 degrees of arc in one hour. Man has divided the Earth into time zones, each of which is centered upon a meridian of longitude evenly divisible by 15. The civil day officially begins when the mean Sun crosses the meridian that lies over longitude 180 degrees west. The continuation of this meridian around the Earth passes over Greenwich, England, and has been arbitrarily chosen as the prime, or zero, meridian, or zero longitude. When the day begins at noon at longitude 180 degrees west, it is midnight at Greenwich, England. This instant is the official starting point of time measurement for each day and is known as Greenwich Mean Time or Universal Time.

From the time zone centered on Greenwich—the zero meridian of longitude—the time belts, each about 15 degrees wide, run westward. The time zone that contains Eastern Standard Time in the United States is centered on the meridian that passes over longitude 75 degrees west. At midnight, Greenwich Mean Time, the Earth still has five hours to rotate before it will be midnight by Eastern Standard Time. Midnight, Greenwich Mean Time, is, then, seven P.M. on the previous day by Eastern Standard Time.

As with all of the time zones, the eastern and western borders of the Eastern Standard Time Zone are somewhat irregular. These irregularities are arranged so that geographical entities, such as states, will not lie partly in one time zone and partly in another. The difference between most time zones is one hour.

In the Nautical Almanac the time zones are not given names; they are designated simply as one hour east or one hour west, and so on, all around the Earth, but the principal cities or islands in each time zone are named. In the more



### Time around the world when it is noon at Greenwich, England, at zero longitude.

populated parts of the Earth the time zones have been named. Centered on the zero meridian is, of course, Greenwich Time. The first time zone west of Greenwich takes in no land except the western edge of the African bulge and Iceland, but Iceland has been included in a more western zone. The time zone of the 30th western meridian is simply two hours west of Greenwich. Then comes the zone of the 45th meridian. This is Greenland Standard Time and covers Greenland and Iceland. Time here is three hours earlier than Universal Time. Then comes Atlantic Time on the 60th meridian, four hours earlier. This is the time zone for the eastern part of Brazil and some Arctic regions. Inside the Atlantic Time Zone is a small enclave that takes in Newfoundland, Labrador, and the adjacent territory. This is Newfoundland Time and is three and one half hours earlier than Universal Time. Eastern Time is centered on the 75th meridian, five hours earlier than Greenwich. Then come Central Time, 90th meridian and six hours earlier, Mountain Time, 105th meridian and seven hours earlier; Pacific Time, 120th meridian and eight hours earlier; Yukon Time, 135th meridian and

nine hours earlier; and Alaska Time, 150th meridian and ten hours earlier. South America, Central America, and Mexico use Atlantic, Eastern, Central, and Mountain Times in appropriate areas.

Across the sweep of the Pacific Ocean, the more prosaic divisions of the Nautical Almanac prevail, although the eastern end of the Soviet Union lies slightly east of the tip of the Aleutian Islands, which have a time zone of their own called Aleutian Time, centered on the 165th meridian west of Greenwich and eleven hours earlier than Greenwich. At the 180th meridian is the International Date Line, where it is noon of the preceding day, as any official day begins at midnight in Greenwich. Across Asia and the South Pacific east of the International Date Line, time is later than Greenwich Mean Time, instead of earlier. In Soviet territory, standard time is advanced by one hour during the entire year for the nine time zones that cover the vast stretch of the Asiatic continent.

There are three time zones in Europe. That centered on longitude 30 degrees east of Greenwich is two hours later than Greenwich Time and is East European Time. Then come Mid-European Time, on the 15th meridian east of Greenwich, and, finally, Greenwich Mean Time again. These three time zones are used over most of Africa.

In many time zones in the United States, by local ordinance, Daylight Saving Time is established during the summer months of long daylight. This is generally one hour earlier than the normal standard time for the given zone. Daylight Saving Time usually begins on the last Sunday in April, when all the clocks in the communities affected are turned ahead one hour, and ends on the last Sunday in October, when the clocks are turned one hour back.

The various divisions of time that are dictated by the apparent motions of objects in the sky seem obvious. It is probable, though not, as far as is known, capable of being proved, that the day was the first time division to be noted



and used by man. The alternate recurrence of light and dark mark off a passage of time that is difficult to ignore. Days pile up rapidly, however, and even in primitive times it must have been obvious that keeping records by tallying the swiftly passing days was too cumbersome a method to be practical. Ask yourself, for example, how many days have passed since your last birthday: unless that day chanced to be no more than a week or so ago, it will take more calculation than you would care to perform regularly to make up the tally. Thus, man must soon have cast about for some larger period of time.

Such a period was ready and waiting for man to notice and use it. At what must have appeared to early man to be regular intervals, the Moon made its way across the sky. It may have taken man thousands of years to realize it, but he eventually learned that there was a relatively stable number of days between one new moon and the next. Again, it seems obvious that the month was the second natural division of time to be used.

The third time division may have been either the week or the year. The week, which bears a close relation to the time between one phase of the Moon and the next, and whose number of days was also dictated by the number of visible moving objects in the sky, may have been easier to discern and understand than the year. The regular but slow cycle of the seasons, the northward and southward march of the Sun from winter solstice to summer solstice and back again, may have taken longer to register on the slow mind of primitive man than the more easily remembered changes of the Moon. It is difficult to say.

In any event, after a few hundred thousand years on Earth, man found himself with days; with weeks whose length more or less approximated modern weeks; with months whose length was regulated by the phases of the Moon; and with years whose length it took him thousands of those same years to learn and which, in the end, caused him considerable

frustration and confusion.

The division of the day into hours began so long ago that it is not possible to set a beginning to the custom. The minute and the second are modern, but the hour is ancient. Many cultures in the past numbered the hours of the day from midnight, as does modern astronomy, and as many more began the day at noon. The day of the Greeks began at sunrise: twelve hours were counted between sunrise and sunset, and twelve more between sunset and sunrise. These hours varied in length as the days changed in length with the seasons. In winter, when the days were short, the hours of the day were short and those of the night were correspondingly long. The reverse was true in summer. Only at the equinoxes was there any measure of equality, for a time, in the hours of day and night.

In many countries little attention was paid to such picaresque matters as hours. The day consisted of sunrise, noon, and sunset, and that was all. The more formal keeping of hours awaited the growth of religious observance and the desire on the part of the Roman Catholic church for a certain regularity of formal worship in the canonical hours.

Whether the number of days in the week came from an approximation of the number of days between the phases of the Moon or from the number of planets—among which the Sun and the Moon were included—it is certain that the names of the days came from the planets, which, in turn, were named for the gods. The Greeks, indeed, had no week, nor did the Romans until well along in their history, but out of the mysterious east, from Chaldea and from Egypt, came the week, born of an attempt to assign every hour of man's existence to the strange wandering stars which were, to these fearful people, the personifications of their gods.

In Egyptian astronomy the hours of the day were assigned to the various planets in the order of the motions of the planets in the sky. The slowest planet, Saturn, was placed

first; then came Jupiter, Mars, the Sun, Venus, Mercury, and the Moon. Thus, if Saturn controlled the first of the twenty-four hours of the day, it would also control the eighth, the fifteenth, and the twenty-second hours. Jupiter would have charge of the second, the ninth, the sixteenth, and the twenty-third hours; and so on. In this case Mars would have the twenty-fourth hour, and the Sun, being next in line, would take the first hour of the next day. The planet ruling the first hour of any day was considered to have general over-all charge of the entire day. Thus, in the example above, the day of Saturn would be followed by the day of the Sun, and the rest of the days in the series can be similarly worked out. It will be found that the order of days was then as it is now. This Oriental arrangement of the days of the week was picked up by the Romans. Here are the days in order with their Latin names:

|              |               |
|--------------|---------------|
| Dies Solis   | Dies Mercurii |
| Dies Lunae   | Dies Jovis    |
| Dies Martis  | Dies Veneris  |
| Dies Saturni |               |

The modern English names for the days have come to us through the Saxon language, in which they were called:

|               |             |
|---------------|-------------|
| Sun's Day     | Woden's Day |
| Moon's Day    | Thor's Day  |
| Tiw's Day     | Frigg's Day |
| Seterne's Day |             |

Tiw was the Anglo-Saxon counterpart of Mars; Woden, of Mercury; Thor, of Jupiter; and Frigg of Venus.

For many hundreds of years man tried to use the cycle of Moon phases as a major time division, beginning each month with the first sighting of the slender crescent of the Moon just after new. The time that elapses between one new moon and the next, or between any two corresponding phases of the Moon is, however, about  $29\frac{1}{2}$  days, on the average. This is a most unhandy and inconvenient figure. No shorter

time interval goes into it evenly, and it does not fit evenly into the year.

Twelve lunar months is 354 days— $11\frac{1}{4}$  days shorter than the tropical year. The major quotient of lunar months in the year did come to twelve, but in order to take care of the remainder, it was necessary to add a thirteenth month, called an intercalary month, every third year; this used up the 34 days that had accumulated during the interval. To avoid this nuisance, man early began to alter the length of the natural month to suit his own convenience. The Egyptians had twelve months of 30 days each and added 5 days at the end of every year. These 5 days were not accounted for in any of the months. The Greeks did much the same thing, but they reckoned their months in three decades of 10 days each, instead of by weeks.

The Romans had an impossibly complicated system. The first of each month they called the kalends. Then they jumped to the fifteenth day of the month, which they called the ides, and worked backward from that point. For example, the tenth of the month was the fifth day before the ides. They did have a minor division of the month called the nones, which was the ninth day before the ides. Then they ran out the month by counting the days in decreasing numbers from the ides to the next kalends.

In the first dim days of the first Roman Empire, Romulus himself is reputed to have established the rudiments of a calendar. He used the lunar month, but he included only ten months in each year. The ten months of Romulus accounted for only 304 days. The year began with March, named for Mars who was at that time the god of fields and harvests and had not yet been given his later warlike character.

Following March came April, the month of burgeoning buds, named from the Latin word *aperire*, which means "to open." May came from Maia, a minor Roman goddess, also

in charge of young growing things. June was named from the Latin *junius*, which means "young." The rest of the months were numbered: Quintilis, Sextilis, Septembris, Octobris, Novembris, and Decembris—the fifth, sixth, seventh, eighth, ninth, and tenth months, respectively. Between December and March was a gap of 61 days that did not belong to any month. It is from this ancient interval of time that belonged nowhere that we get the expression "the dead of winter."

Not long after Romulus, under the early Roman emperor Numa, two months were added to fill this gap. One of these, January, was inserted at the beginning of the series, before March, and the second, February, was put in at the end of the year, after December. January got its name from Janus, the two-faced god of gates and entrances, while Februarius was the deity who managed atonement for minor everyday misdeeds. After a few years, however, the position of the two months was changed. January, from the very personality of its god, remained in first place, while February, in spite of its connotation of repentance for a year's peccadillos, was placed in second position, early in the year. December, in spite of the decimal implication of its name, was given its present position as the twelfth month. The Romans still used the lunar month, however, and threw in an intercalary month, called Mercurius, every third year, between the twenty-third and twenty-fourth day of February. Meanwhile, according to the Roman reckoning, the year consisted of 365 days.

Because of this error, by the time Julius Caesar had assumed the rule of Rome, December was enjoying autumn weather and April was freezing in winter. Caesar, with the dubious help and advice of a Greek astronomer named Sosigenes, settled the entire problem of the out-of-step calendar with one mighty swing. First of all, he decreed that the current year, the 708th year since the founding of Rome (which we count as the forty-sixth before the birth of Christ) should have 445 days in order to bring calendar and seasons back

into coordination. This remarkable year was called the Year of Confusion. Caesar further announced that the normal year contained not 365 days, but 365 days and a quarter of a day, and that every fourth year should, therefore, have 366 days, and that future confusion would thereby be avoided.

As a pat on the back for this and for other favors he had conferred upon the Roman people, the month of Quintilis, which had 31 days, was renamed Julius, in Caesar's honor. A few years later Caesar's nephew, Augustus, not to be outdone by his uncle, gave his own name to the month of Sextilis and, to put his month on an equal footing with the month of Julius, he gave Augustus 31 days as well, taking the extra day he needed from February.

When the Romans had finished reforming the calendar, there were twelve months in the same order and with much the same individual quota of days that we have now. There were ordinary years of 365 days and a leap year of 366 days every fourth year. After several decades, however, it became apparent that Caesar had been too generous with his leap years. The calendar again began to fall out of step with the seasons, but in the opposite direction from the original discrepancy. As man's ability to measure time improved, he found that the year was not exactly  $365\frac{1}{4}$  days long, but that it measured 365 days 5 hours 48 minutes 46 seconds. It is true that this is only 11 minutes 14 seconds short of Caesar's reckoning, but that brief difference adds up to a day every 128 years.

In 1582, when this slight deficiency had amounted to 10 days, Pope Gregory suggested a second calendar reform. He advised the dropping of the 10 days that had accumulated since Caesar's change, and declared that only those century years that were evenly divisible by 400 were to be leap years thereafter. Thus, 1600 was a leap year, but 1700, 1800, and 1900 were not, although they were evenly divisible by 4 and

thus qualified under Caesar's rule. The year 2000 will be a leap year. This change was made, and we now live under the Gregorian calendar, as do most modern countries. The Gregorian calendar still leaves 26 seconds every year unaccounted for, and by a slow process these few seconds will amount to a full day every 3,323 years. This is not far from being 4,000 years, so it has been suggested that every year that is, by its number, a multiple of 4,000 be a common year instead of a leap year. If Gregory had made every 128th year a common year, no matter what treatment its number called for, all of this would have been avoided, but such a division would not have been as easy to remember as the present system of dropping leap year every fourth century. Let us hope that someone will remember to take care of A.D. 4000 when it finally rolls around.

Man's efforts to keep track of minor divisions of time are relatively new. He was satisfied at first to enumerate the three major divisions of the day—sunrise, noon, and sunset. Sundials then made it possible for him to count the intermediate hours whenever the weather permitted. For those hours that the Sun could not number, various other devices were employed: candles marked with alternate black and white bands, each of which took approximately an hour to burn; vessels holding water that was allowed to leak more or less uniformly, lowering a float past hour marks; glass arrangements in which sand was allowed to fall from one receptacle into another in a definite period of time—the hourglass—although most of these were calibrated to perform in a much shorter time than an hour. All of these helped man to count the moments fleeting past him.

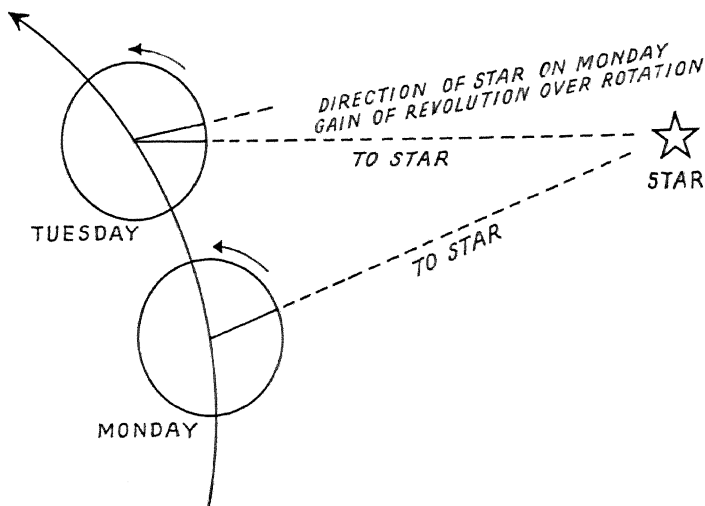
Late in the sixteenth century, Galileo Galilei discovered that a pendulum of a given length vibrated constantly—that is, it swung from one end of its arc to the other in exactly the same period of time regardless of its weight or the material of which it was made—and the longer the pendulum was,

the longer was the period of time through which it swung. A few years later Christian Huygens applied this principle to a device for keeping time, using the pendulum to release the power in a coiled spring, little by little, so that a pointer could be rotated to sweep around a calibrated dial. Not long after that a second pointer was added, moving in twelve revolutions to one revolution of the original pointer; and the clock with its hands evolved, measuring minutes as well as hours. From that beginning, clocks have been refined and improved until a fine pendulum clock so made that the pendulum is self-compensating and will adjust for changes in its length due to temperature variation will keep time to within 1 second in 1,000,000 seconds.

For timekeeping with an even smaller margin of error, man is now using the natural vibration of certain molecular combinations, such as ammonia, and even of isolated atoms, like cesium. Timepieces built around these immutable characteristics should not vary more than 1 second every three hundred years.

During the time in which the Earth is making one complete turn upon its axis, it is also moving in revolution about the Sun. In one year the Earth completes its journey around the Sun, moving through 360 degrees of arc. In one day, then, the Earth moves through slightly less than 1 degree of arc. Because the rotation and revolution of the Earth are in the same direction, the Earth's revolution causes it to gain upon its rotation this fraction of a degree every day. If we find that a certain star is in a certain position relative to the Earth at a given instant on one night, we might expect the same star to be in the same position precisely 24 hours later. The Earth, however, will have gained on the star by the small amount it has progressed in its annual revolution, and the star will therefore reach the same position relative to the Earth, not 24 hours later, but 23 hours 56 minutes 4.09 seconds later. This interval is the sidereal day, calculated by





**The Earth's progress in revolution each day gains upon the stars.**

sidereal time which is based on the stars rather than on either the apparent or the mean Sun.

The mean solar day—the day by which we live—is thus correspondingly longer than the sidereal day and contains 24 hours 3 minutes 56.56 seconds of sidereal time. Astronomers, whose chief concern is with things celestial, must use sidereal time in locating their quarry. Each celestial object has, at a given time, its location on the apparent inverted bowl men call the sky—the celestial sphere. This apparent sphere is divided into units of north-south and east-west measurement which correspond to latitude and longitude upon Earth. The east-west direction on the celestial sphere is called right ascension, and the north-south direction is declination.

Right ascension is measured in units of hours, minutes, and seconds of time because the Earth turns completely under the entire celestial sphere every twenty-four hours. Right ascension, then, has twenty-four major divisions, one for each hour, beginning with zero—or 24—and continuing always

eastward completely around the celestial sphere. Each of these hourly divisions is subdivided into minutes and seconds—sixty in each. The starting point of right ascension is that place in the sky where the ecliptic crosses the equator from south to north. The Sun reaches this point in its apparent journey around the Earth about the twenty-first of March every year, on the first day of Spring. This location is the vernal equinox.

When man first began to calculate with some accuracy the various positions of the Sun at different times of the year, the vernal equinox lay before the stars of Aries, the Ram. For that reason, the vernal equinox is also called the First Point of Aries, or the First of Aries. The precession of the equinoxes has moved the vernal equinox westward until it is now far inside the constellation of Pisces, the Fishes, but it is still called the First Point of Aries, and its symbol is the symbol for Aries ( $\gamma$ ).

From this arbitrary beginning point, astronomical star positions are measured always to the east, and never to the west, around the celestial sphere. The first hour of right ascension is one hour east of the vernal equinox; the twenty-third hour of right ascension is twenty-three hours east of the vernal equinox and is never spoken of as being one hour west of it. The position of every celestial object in right ascension is expressed by a coordinate written as a number of hours, minutes, and seconds of time. The difference between this number and the vernal equinox is called the hour angle of the object in question and tells, of course, how far east of the vernal equinox it may be found. The distance of a celestial object north or south of the celestial equator is its declination and is expressed in degrees, minutes, and seconds of arc. The celestial equator lies directly above the terrestrial equator, and the celestial poles are directly above the terrestrial poles. Declination corresponds to latitude. Declination at the celestial equator is zero; degrees north of the celestial equator

are expressed as plus, and those south of it as minus. At the north celestial pole, declination is 90 degrees north, or  $+90^\circ$ ; at the south celestial pole, declination is 90 degrees south, or  $-90^\circ$ .

Astronomical time begins at midnight and is calculated from the position of the mean Sun plus twelve hours. When the mean Sun is on the meridian, it is twelve hours mean solar time, or noon. When the meridian happens to be the one lying over Greenwich, England, it is noon, Universal Time, and simultaneously it is midnight, Universal Time at the 180th meridian, at the International Date Line somewhere near the middle of the Pacific Ocean.

Sidereal time is reckoned not by the Sun, but by the vernal equinox. The sidereal day is the interval between successive passages of the vernal equinox across the meridian. Because this passage takes less than twenty-four hours, occurring 3 minutes 56.56 seconds earlier every day, sidereal time begins to gain over civil time from the twenty-first of March on, and is an entire day ahead of civil time when a year has passed. On March 21, for example, there occurs an instant when the Sun appears to be over the celestial equator at the vernal equinox, and sidereal time and civil time are nearly the same. Six months later the Sun is again over the equator, but this time it is at the autumnal equinox at 12 hours right ascension, and is thus 12 hours, or 180 degrees, removed from the vernal equinox. When the vernal equinox crosses the meridian on September 22, it is about midnight by mean solar time.

An essential instrument in any observatory is a sidereal clock. Such a clock has a dial that is calibrated in twenty-four hours instead of twelve and is regulated so that its hands complete the circuit of its dial in 23 hours 3 minutes 4.04 seconds of civil time. When a sidereal clock reads zero—or 24—the astronomer knows that the vernal equinox is on his meridian. Since the vernal equinox is the east-west reference

point for every object in the heavens, he has a good idea of the general east-west location of them all.

When man leaves the Earth, he must take his own time with him and depend upon the mechanical accuracy of his clocks. On any of the three bodies in the solar system where it may be possible for him to exist, he may be able to adjust to a natural time period similar to the one he has developed on Earth. On the Moon, for example, there will be sunrise, noon, and sunset, although six or seven terrestrial days will intervene between these time divisions. There will also be differences of as much as seventeen hours in the lengths of these Moon time intervals now and then, so that man will again have to invent and depend upon a fictitious mean Sun and his own mechanical devices to keep accurate time there.

Venus will certainly present new problems. The eternal cloud cover of Venus will prevent observation of the Sun from that planet. There may be alternate periods of light and dark, but these will be without definite boundaries upon which accurate measurements can be based. How long these alternating periods are upon Venus, we do not know. Venus has given us no definite clues as to the speed of its rotation, and estimates range from a short period of about 30 Earth days to a situation in which Venus rotates in the same period of time that it revolves—225 Earth days. If the last condition is correct, there will be no alternation of light and dark from any one spot upon the surface of Venus, for the same side of the planet will always face the Sun, and the opposite side will be in eternal darkness. It appears that timekeeping on Venus will be a matter of purely mechanical devices.

On Mars timekeeping will be more like timekeeping on Earth. The Martian day is 24 hours 37 minutes 24 seconds of Earth time. Minor adjustments in terrestrial timepieces would suffice to keep reasonably accurate time on Mars. The periods of time longer than the day will be those that give difficulty. The year on Mars contains 687 Earth days, or 669

Martian days, so that man on Mars would have much the same difficulty in allocating lengths to his months as he had on Earth. He could have twelve months, three to a season, but three of the twelve months would have to contain fifty-five days, and nine of the twelve, fifty-six days each. His seasons would still be four in number, but since the variation of Mars's distance from the Sun during the year is greater than that of the Earth, there would be a greater disparity in seasons on Mars. The polar axis of Mars is inclined at about the same angle from the plane of its orbit about the Sun as is the polar axis of Earth; estimates run from about 25 degrees to slightly less than 24 degrees. The pole star of Mars would be a star of third magnitude in the constellation of Cygnus, the Swan—Zeta Cygni—and it would be about as far from true north on Mars as Polaris is on Earth. Because of the wide swings that Mars accomplishes in its orbit about the Sun and the resulting variations in the velocity of Mars during its year, man would almost certainly be forced there to the same subterfuge of a mean Sun that he has adopted here.

There are natural timekeepers in space that do not depend upon the motion of the Earth and that need only to be seen to be used. These are the variable stars, and they may be divided into two general groups. There are the eclipsing, or extrinsic, variables, whose variability depends upon the motions of two stars in the same gravitational system, and the intrinsic variables which change in brightness because of some internal cause inherent in a single star. Among the intrinsic variables there have been found many stars whose light varies with ceaseless regularity in periods ranging from a few hours to about forty days. The selection of one of the short-period variable stars could provide a check upon the mechanical rate of change of clocks used by far-ranging astronauts.

## Theories of Origin

LONG BEFORE MAN had any idea of the real nature or extent of the universe that surrounded him or of the tiny group of captives of the Sun among which he lived, he was driven by an urge to account for it all in some way. The legends of primitive people are filled with imaginative and fanciful accounts of the Creation. Religious writings put forth more dignified but equally imaginative portrayals of the beginnings of the universe. It is only within the last two hundred years that man has attempted to present hypotheses of the origin of both the universe and the solar system that have a scientific basis.

Exactly what was it for which man was trying to account? There is a star, the Sun, and around that star, in orbits that are nearly circular and that, with one exception, deviate by only a few degrees from the same plane, revolve nine major planets and a large but unknown number of minor planets, or asteroids. Attached to some of the major planets is a total of thirty-one known satellites. Also moving around the Sun, but in orbits of almost all inclinations—at all angles and in all directions—are myriads of tiny solid particles, the meteors. In a sort of outer haze embracing all the rest of the system is a shell of small frozen objects, circling slowly about the Sun at enormous distances. These are the comets. Occasionally a comet, pulled out of this enveloping cloud, is

diverted into an eccentric orbit that takes it deep into the center of the system, around the Sun and out again almost to its original location.

Of the nine planets, four are near the Sun. These four are all compact, very dense, revolving rapidly and rotating slowly in the same direction, and all of them have scanty if any atmosphere. Farther out and widely separated from one another are four giant planets, great swollen tenuous bodies with slow revolution and rapid rotation and with deep, dense atmospheres. The ninth planet, at the greatest distance from the Sun, does not conform to this pattern. Its orbit deviates most widely from the general plane of planet orbits; it is small, in the size group of the four inner planets; it has no atmosphere, and it rotates slowly. It is out of place, and we may discount it, for it probably started out not as a planet but as a satellite of one of the giant planets.

All of these objects move about the Sun in conformity with immutable laws which all objects in space obey. They are made of materials that must also obey certain laws depending upon the temperature in which they exist and their consequent condition. We shall consider these laws as we encounter them.

The earliest serious attempt to account for the origin of the solar system came from the great German philosopher, Immanuel Kant. Kant had a solid education in the physical sciences, and, in 1755, when he was thirty-one years old, he published anonymously a pamphlet that he called *Allgemeine Naturgeschichte und Theorie des Himmels* ("General Natural History and Theory of the Heavens").

In this book Kant stated the hypothesis that all of the material in the solar system was once in the form of a cloud of tenuous gas that filled uniformly the space that the solar system now occupies. Because all of the known elements were present in this cloud, its uniformity was soon distorted as the attraction of the heavier elements drew the lighter

elements to them, thus building up a number of larger masses. The forces of collision between these larger masses and those smaller masses that were attracted to them, gradually imparted a rotary motion to the cloud. The heavier elements continued to grow and, by this accretion, became the centers of many nuclei moving about the center of the cloud.

The number of these heavier nuclei was gradually reduced by repeated collision and by the absorption of smaller nuclei by the larger. The system thus developed into a number of bodies moving in orbits about the largest single mass, which remained in the center of the system. This general picture painted by Kant has remained the basis for most of the widely accepted modern hypotheses.

This is perhaps a good place to pause for a moment to take a look at those physical laws that have proved to be the barriers against which many theories have been shattered. The first of these hurdles is the kinetic theory of gases. Gases do not have a tendency to rush together and coalesce. Gases disperse. The molecules of gas fly apart, and the greater the temperature, the more enthusiastically the various molecules speed away from each other in all directions. All the elements progress from solid states to become gases as they are subjected to higher temperatures.

The second pitfall is the law of the conservation of angular momentum. The angular momentum of a moving body, such as a planet revolving about the Sun or a particle on the surface of a planet being carried around by the rotation of the planet, is based upon the mass of the revolving body, the square of its distance from the center of its revolution—the radius of its revolution—and the velocity at which it is moving. The conservation of angular momentum dictates that the total angular momentum of a body or of a system must always be the same; it cannot be changed. If one or more of the three factors is changed, one or more of the remaining



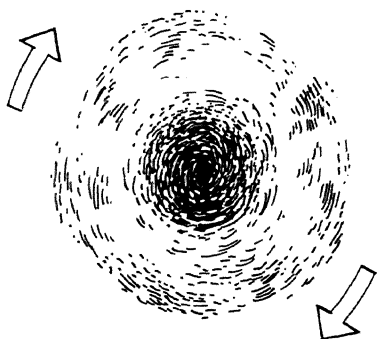
factors must also be altered to compensate for that change and thus maintain the total angular momentum of the object or system involved.

The example most often used to illustrate the conservation of angular momentum is that of a skater who is pirouetting—spinning about in one position. She—who would bother to watch a male skater?—has her arms outstretched and spins fairly slowly. The angular momentum of her hands is made up of the mass of her hands, the square of the distance that they are from the center of her body, at the end of her outstretched arms, and the rate at which she is spinning.

The spinning skater now draws her hands toward her body and holds them close. As she does this, the rate at which she is spinning is accelerated although she has done nothing else to speed it up. When she shortened the distance between the center of her body and her hands, however, she altered one of the factors governing the angular momentum of her hands. The mass of her hands could not change, but their rate of spin about the center of her body had to change in order to compensate for their change of position and thus preserve the total of their angular momentum.

So it would be, for example, with a sphere of gas. The total of the masses of all the molecules of gas that made up the sphere, their distances from the center of the sphere, and the velocity at which they were revolving about the center of the sphere would produce the total angular momentum of the sphere. If the sphere were to shrink, the distances of the molecules from the center of the sphere would be less than when the sphere was larger, and the sphere would have to spin more rapidly than before in order to preserve its angular momentum. Any theory of the formation of the solar system must conform to the law of the conservation of angular momentum and to the kinetic theory of gases.

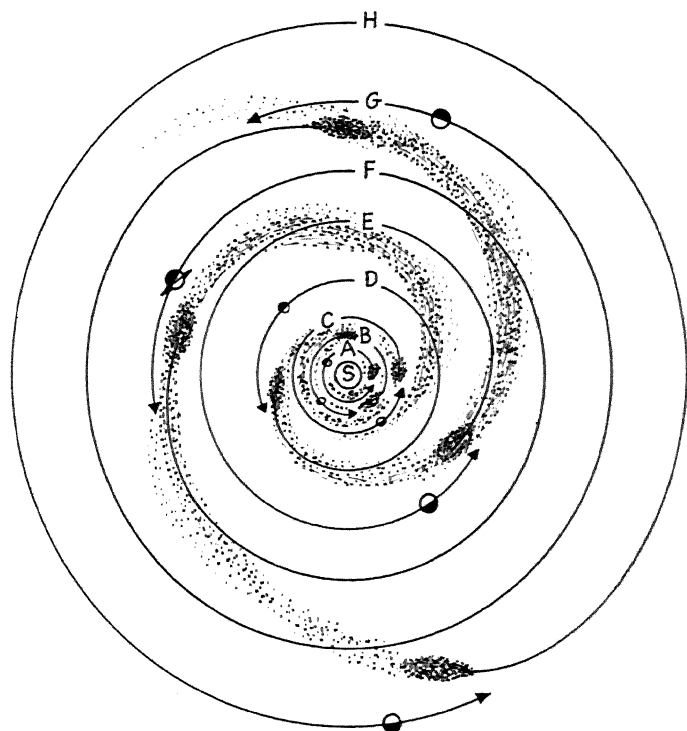
The hypothesis of Immanuel Kant did not, evidently, attract much attention, nor did it become widely known, for



**The theoretical formation of rings about a central condensation, according to the nebular hypothesis.**

about forty years later a great French mathematician and astronomer, Pierre de Laplace, the author of *Mécanique céleste*, presented a theory that had some remarkable resemblances to that of Kant. Laplace's nebular hypothesis was published in 1796. It presents, as does the theory of Kant, the picture of an enormous sphere of gas that is slowly spinning from west to east. The gas gradually cools, shrinks, and, as it shrinks, spins more rapidly. This increase in angular velocity—the rate of spin—sends much of the material in the cloud to its equator and diminishes the amount at the poles of its rotation.

As its rate of spin increases, the angular velocity of the material in its equatorial bulge becomes equal to or exceeds the gravitational attraction that the sphere exerts upon the material. When this happens, the material in the outer portion of the equatorial bulge breaks away from the main body of the gas cloud and remains in place, not following the continued shrinkage of the central part of the cloud. This process repeats itself several times, so that a succession of concentric rings is finally left around a small central sphere. The gases in each ring gradually assemble into spheres and condense into the planets. The small central mass remaining becomes the Sun.



A. MERCURY B. VENUS C. EARTH  
 D. MARS E. JUPITER F. SATURN  
 G. URANUS H. NEPTUNE  
 S. SUN

**The planets were born in a miniature spiral nebula.**

The nebular hypothesis was received with much applause and a feeling of great relief. Here was one of the greatest mathematicians of the age who had at last come to the rescue of mankind and revealed to him the origin of his home. The nebular hypothesis fitted fairly well in many respects with the regular and orderly behavior that was all that was then known of the captives of the Sun. Indeed, Saturn and its rings appeared to provide an excellent example of the entire arrangement in operation.

As man's knowledge of the various members of the solar system and of the details of their motions increased, however, several flaws appeared to mar the smooth reasoning of this plan. When Neptune was discovered, in 1846, it was calculated that the ring that must have separated from the central cloud to form Neptune would require so much angular momentum that the total would amount to more than two hundred times the angular momentum actually present in the entire solar system.

It has also been pointed out that the orbits of the planets about the Sun must be in exactly the same plane if the nebular hypothesis is correct. The solar system is flat, it is true, but not sufficiently flat to have originated in the manner suggested by Laplace. The orbits of Mercury and Venus deviate from the plane of the Earth's orbit by 7 and by 3.4 degrees, respectively, and the orbit of Pluto by more than 17 degrees. If the orbits of all the planets ever had been in the same plane, they would still be there. There are no influences that could possibly give any of them different inclinations from those required by the nebular hypothesis. They might be accelerated or slowed down in their revolutions about the Sun; they might be drawn farther from the Sun than their original positions or pushed closer to it; but they could not be lifted above or forced below their original planes.

The nebular hypothesis also required that the central Sun be rotating at a high rate of speed, whereas the present lazily turning Sun provides only 2 per cent of the total angular momentum of the system. There is one factor that could account for the Sun's lack of angular momentum at present, but that could provide for its having a much greater percentage originally. This factor has lent some strength to this portion, at least, of Laplace's theory. The Sun, like the Earth, and probably like all other bodies in space, is a magnet. At a time close to the final stage of the processes outlined in the

nebular hypothesis, the Sun would be a rapidly rotating body with a strong magnetic field that rotated with it. Surrounding the Sun, there would be a cloud of particles left over after the formation of the planets had been completed. These particles would be revolving about the Sun in accordance with the laws formulated by Kepler which govern the motions of bodies in space. Particles near the Sun would move more rapidly than those farther from it. These particles would themselves have magnetic forces resembling those of the Sun and would, in their revolution about the Sun, combat the revolving magnetic field of the Sun. This conflict of forces would create a drag—a braking effect—that would slow down the rotation of the Sun and would, in so doing, transfer angular momentum from the Sun to the particles. This transfer would continue until the rotational speed of the Sun became identical with the velocity of the cloud of particles. The original angular momentum of the individual planets, however, would not be changed.

To cap the objections to the nebular hypothesis, gaseous rings formed as Laplace stated would disperse and fly apart into space, and would not coalesce into planets. The holes shot into the nebular hypothesis by an increasing knowledge of physical laws and of the complexities of the solar system made scientists shy away from similar theories for more than one hundred years.

At about the turn of this century, two men at the University of Chicago published the planetesimal theory of the formation of the solar system. Dr. Forest Ray Moulton was professor of astronomy at the University of Chicago and a research associate of the Carnegie Institution of Washington, D.C. His colleague, Dr. Thomas Chrowder Chamberlin, had been president of the University of Wisconsin and was professor of geology at the University of Chicago. His study of geology and his knowledge of the Earth's physical history showed him the defects in the nebular hypothesis and led

him to collaborate with Dr. Moulton in the planetesimal hypothesis.

The planetesimal hypothesis was built about the picture of a cloud of planetesimals revolving about a central mass, in orbits that were elliptical and that were also at many inclinations—not all in the same plane. Planetesimals are tiny planets, ranging in size from submicroscopic particles to large planetoids or asteroids. The picture of such a cloud grew from the spiral nebulae which had been seen in space and were then believed to be clouds of gas and dust among the stars. Astronomers were turning up more and more photographs of these clouds, most of which had a certain similarity of formation. They differed from the gaseous diffuse nebulae in that they all seemed to have a flat, disklike form, with a relatively slight thickening at their hubs, and they were obviously in rotation about a central point.

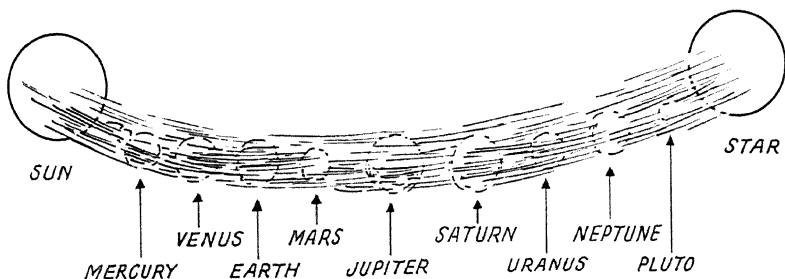
In the spiral nebula that formed about the central mass that became the Sun, there were local condensations. These, because of a larger gravitational influence born of their relatively greater mass, constantly swept up other smaller planetesimals and smaller condensations in their paths and thus grew into planets and satellites. Still other planetesimals fell in a steady stream into the central mass, adding to the amount of material that became the Sun.

In this theory, solid particles—the planetesimals—were substituted for gases in order to avoid one of the factors that upset the nebular hypothesis. This was the kinetic theory of gases. Planetesimals, because they were solid, would not fly off into space as would gases. The problem of angular momentum was also avoided by the same substitution. The rotating spiral mass possessed originally the same angular momentum as did the solar system because no excessive velocity of rotation was required to separate the various planetary rings from the central mass, which was needed in

the earlier theory. The planetesimal hypothesis also provided for minor variations from one universal plane of revolution for the planets and furnished, at the same time, the possibility for a number of orbits of high inclination for the smaller bodies, because these smaller bodies were out of the paths of the more massive planetesimals and would not be swept up and absorbed by them. All of these points seemed to avoid the weaknesses of the nebular hypothesis, and the theory of Moulton and Chamberlin appeared to be much more acceptable.

The problem now was to account for the spiral nebula—the rotating cloud of dust around the central mass. This problem was becoming more acute with the discovery, in some of the spiral nebulae, of what were almost certainly fully formed stars in their outer regions. As telescopes became more efficient, some of the spiral nebulae began to appear more like clouds of stars rather than clouds of dust and gas. In order to surmount this obstacle, the authors of the planetesimal hypothesis produced a sort of codicil to their original theory, but this codicil plunged them again into the two ancient pitfalls of the kinetic theory of gases and the law of the conservation of angular momentum. They came up with the tidal theory.

The tidal theory was based upon the supposed close approach of a second star to the Sun, which was at the time free from any encumbrances or captives. The close passage of this second star raised tremendous tides in both the Sun and the passing star. The material in these great tidal waves was torn from both stars by the turmoil of their passing, streamed out into space between the stars, and was carried into a path around the Sun by the course of the passing star. Some of this material was carried off by the star, some of it dissipated into space, and some of it was retained by the Sun. The material about the Sun condensed into planetesimals and



**Grazing collision between the Sun and a passing star draws from each the material that became the solar system.**

continued to revolve about it. Such of this material that did not condense served to reduce the eccentricity of the orbits of the larger masses by tidal friction and provided for the orbits of higher inclination of the smaller bodies of the solar system.

Here we have again the two old bugaboos raising their ugly faces with sardonic grins. Gas so ripped from a star would not condense, but would speed into space with explosive force. If the grazing star were to approach the Sun sufficiently close to draw material from the Sun, it would not provide the angular momentum to the Sun to account for the angular momentum that was finally left in the solar system. If it passed at a distance that would provide the correct amount of angular momentum, it could not have raised the necessary tides to provide the material. Furthermore, the chances of a near miss between two stars was so remote that it was almost unthinkable. Moulton and Chamberlin not only had revived the two previous imps, but had created a third almost as strong, to mitigate against the probability of their hypothesis.

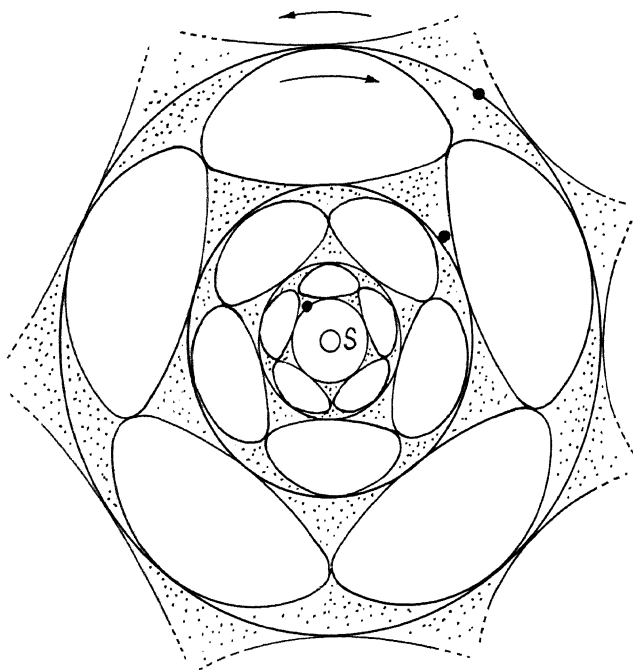
There seemed to follow now a sort of wild scramble to save the best features of the previous hypotheses and to alter them to fit the requirements of physical laws. The Sun was declared to have had at one time a companion star at about the distance from it of the planet Jupiter. This was reasonable. About 40 per cent of all the stars we know of in our observable part of space are either double or multiple stars. This companion star, then, was the one that collided with the out-



side star, as described in the tidal theory, and the debris of the collision, which carried the wreckage of the Sun's companion star out of our ken, became the cloud of planetesimals that surrounded the Sun and developed into the solar system. This account of the origin of the system did not preserve much of the bits and pieces of previous theories. The debris from such a collision would be most unlikely to attach itself to a star close at hand—the Sun—but would follow the kinetic laws of gases and make off into space in all directions. Such a collision, according to Dr. Robert Baker, professor of astronomy at the University of Illinois, would be a fine way to start an explosion, but not a good way to start a planetary system.

A similar theory involving a companion star to the Sun supposed that the companion star became a supernova—a star that exploded because of some imbalance in its complicated atomic structure. The debris of such an explosion, again composed largely of gas but with some mixture of dust, was hurled into space but kept together to some extent in an expanding cloud. Some of it was captured by the Sun and became the swarm of planetesimals necessary to start the evolution that formed the solar system. This theory might hold if there were sufficient dust in the debris of the exploding star. The gas would disperse itself rapidly. Here again, however, we face the high improbability of such a chain of circumstances.

A recent theory propounded by C. F. von Weizsacker, the German astrophysicist, again involves similar elements of the various nebular theories. The Sun, already in existence as a star, was surrounded by a disk-shaped cloud of gas. This cloud conformed to the laws of planetary motion in that those parts of it more distant from the Sun were rotating more slowly than the regions nearer to the Sun. This variation in rotational speed of the different parts of the cloud created eddies in the cloud similar to those eddies in a brook when a bay or a cove in its bank creates a backwater past which the



**The sweep of particles moving about the Sun  
creates eddies between the principal streams.  
In the eddies, the proto-planets roll  
like ball bearings.**

main current of the brook runs more swiftly. Such eddies or turbulences formed vortices between the current and the backwater—that is, created tiny whirlpools in which the gas spun around but did not go anywhere. This condition may also be compared to a ball-bearing race, in which the ball bearings rotate rapidly so as to aid in the passage of two metal surfaces that are moving at different speeds and that might create friction between each other if the ball bearings were not there.

The vortices created, since they remain in one general position, gradually condensed to form proto-planets—the materials from which planets ultimately develop. The stresses set up

in the gas cloud between the proto-planets and the rest of the cloud have a tendency to equalize the different rates of rotational velocity—to speed up the outer regions of the cloud and slow down the inner regions—until the angular momentum of the entire cloud is distributed as it is in the present solar system—with most of the angular momentum in the outer regions. The Sun, which was there to begin with and had its own quota of angular momentum, had no part in the proceedings.

Dr. D. ter Haar, of Purdue University, has suggested modifications of von Weizsacker's theory in order to account for the varying physical characteristics of the different planets. He plays down the vortex theory which is a major part of the first picture, and he supposes the planets to have been formed by material in the cloud which condensed into nuclei and increased in mass by sweeping up more and more small bits, much in the manner of part of the planetesimal theory. In those planets that were forming near the Sun, certain organic compounds were kept from the concentrations by the high temperatures. Those compounds that did form were dense and heavy and became the small, solid, slowly rotating inner planets—Mercury, Venus, Earth, and Mars. Farther from the Sun the lower temperatures permitted the formation of planets that retained organic compounds and grew into the large planets with extensive atmospheres and high rotational speeds—Jupiter, Saturn, Uranus, and Neptune.

Those fairly recent theories that involved a companion to the Sun, which either was the target for a wandering star or became itself a nova, seem to have struck a chord in the minds of many astronomers. There are many double and multiple stars, at least in our own neighborhood of space. Dr. Gerard Kuiper has shown that the distance between the components of a binary system—double stars that belong to the same system and revolve about each other—ranges from  $\frac{1}{100}$  of an astronomical unit to about 100,000 astronomical units.

An astronomical unit, we remember, represents the mean distance between the Earth and the Sun, about 93,000,000 miles. The average distance between the components of a binary system is about 20 astronomical units, which is also the average distance between the major planets and the Sun.

There is also a vast number of stars in space which are very much like the Sun in chemical composition and which, also like the Sun, rotate slowly. If stars do develop from the concentration of nebulae or dust clouds, they would in most cases rotate very rapidly. Since nearly all apparently single stars do, however, rotate slowly, it may be that they have been subjected to the braking effect of having to drag small particles surrounding them across their magnetic lines of force, as we described earlier. Perhaps the same forces that form stars in pairs or in groups were at work in the cases of single stars, but in some manner one of the stars failed to complete its formation and became, instead, a group of planets. This raises the possibility that many of the apparently single, slowly rotating stars may have captives, as does the Sun.

In our galaxy there are many clouds of dark, obscuring matter: dust that seems inert and that hides from us the light of stars lying beyond them. In other galaxies, particularly in those spiral galaxies with definite arm structure, dust is also visible. Sometimes it outlines the arm structure of the galaxy as we see it almost in plane. In those galaxies that are presented to our view edgewise, the dust makes a dark line, a streak dividing the galaxy and cutting through the central plane.

This dust is composed of individual particles that are sub-microscopic—about one hundred thousand grains to the inch. Particles of this size are subject to stellar radiation and can be driven physically away from a strongly radiating star. When these particles are crowded together and in the vicinity of a star, each particle would cast its tiny shadow out into space on the side of it away from the star. This shadow would

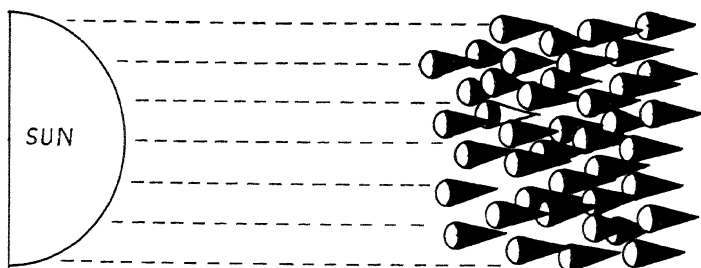


**The Horsehead Nebula in Orion. I.C. 434.  
(Bernard 33).**

shelter a second particle, behind the first particle, from the radiation of the star and would thus prevent its being driven away from the star. The nearer of two such particles, however, would be pushed away and would collide with and adhere to the particle it was sheltering, thus forming a mass larger than the average. This larger mass would, in turn, offer more shade and thus collide with more and more particles and grow constantly. With growth would come stronger



Spiral nebula, or galaxy, in Ursa Major. M 81 (N.G.C. 3031).



**Cosmic dust grains are affected by stellar radiation.**

gravitational attraction and, finally, pressure in the interior of the growing mass, where the gravitational force of the mass was centered. In time, pressure would cause an increase of temperature. When the temperature had risen sufficiently the atomic processes that give life and light to a star would begin.

There is hardly any photograph of a bright nebula that does not show clumpings of dust, little spots that may possibly be made by the accretion of particles. As such an accumulation of dust becomes a star, there will be minor turbulences within it, but the mass will not necessarily rotate. Condensations of minor clumpings will develop in the proto-star or will be drawn into it from the outside. They will grow by the same processes as the proto-planets grew, by sweeping up lesser accumulations or by attracting them gravitationally. At a critical point in this process, the entire mass will collapse, leaving the proto-planets outside the central condensation, which becomes the central star. The planets will develop satellites by the same accretion processes by which they themselves were formed.

A system formed through such processes would possess most of the factors required by physical laws. The direction of revolution of the various members of the system would be determined by the original motion of the proto-planets, as would the shapes of their nearly circular orbits. The proto-planets would rotate in the same direction in which they

revolved about the central star, because they would encounter more material on the faces that were turned toward the central star. Before they solidified, the shaded parts of the proto-planets would move more rapidly than those parts that were illuminated. Asteroids and meteors may be fragments of proto-planets that had orbits of high inclination and hence tried to cut across the mainstream of revolution and were shattered into bits by collisions. Retrograde satellites are probably latecomers, asteroids that have been captured by the larger planets.

To summarize all this, we do not yet know where it all came from. There is no theory that is wholly acceptable or that does not somewhere run counter to some physical law. It is still possible that the entire entourage may have been captured by the Sun which thus gave a home to certain wandering, aimless, cold worlds. Sir Harold Jeffreys, of St. John's College, University of Cambridge, said:

"The problem confronting us is not one of seeking a nice convincing way in which the planets may have originated. Rather it is to explain the fact that the solar system exists at all! The most promising schemes have been tried and found wanting. Now we must turn to those that are highly improbable.

"But the great trouble is to find even a single solution with any degree of probability whatever!"



# **Appendix**



## ORBITAL ELEMENTS OF THE PLANETS

| <i>Name</i> | <i>Mean Distance<br/>Astron. Units</i> | <i>Mean Distance<br/>Miles</i> | <i>Period of Revolution<br/>Sidereal</i> | <i>Period of Revolution<br/>Synodic</i> | <i>Eccentricity<br/>of Orbit</i> | <i>Inclination<br/>to Ecliptic</i> |
|-------------|----------------------------------------|--------------------------------|------------------------------------------|-----------------------------------------|----------------------------------|------------------------------------|
| Mercury     | 0.3871                                 | 35,960,000                     | 87.969D                                  | 115.88D                                 | 0.206                            | 7° 0'                              |
| Venus       | 0.7233                                 | 67,200,000                     | 224.701D                                 | 583.92D                                 | 0.007                            | 3 24                               |
| Earth       | 1.0000                                 | 93,000,000                     | 365.256D                                 | .....                                   | 0.017                            | 0 0                                |
| Mars        | 1.5237                                 | 141,600,000                    | 686.980D                                 | 779.94D                                 | 0.093                            | 1 51                               |
| Jupiter     | 5.2028                                 | 483,300,000                    | 11.862Y                                  | 398.88D                                 | 0.048                            | 1 18                               |
| Saturn      | 9.5388                                 | 886,200,000                    | 29.458Y                                  | 378.09D                                 | 0.056                            | 2 29                               |
| Uranus      | 19.1820                                | 1,783,000,000                  | 84.015Y                                  | 369.66D                                 | 0.047                            | 0 46                               |
| Neptune     | 30.0577                                | 2,794,000,000                  | 164.788Y                                 | 367.49D                                 | 0.009                            | 1 46                               |
| Pluto       | 39.5177                                | 3,670,000,000                  | 247.697                                  | 366.74                                  | 0.249                            | 17 9                               |

## PHYSICAL ELEMENTS OF THE PLANETS

| <i>Name</i> | <i>Mean Diameter<br/>Miles</i> | <i>Mass = <math>l</math></i> | <i>Density<br/>Water = 1</i> | <i>Period of<br/>Rotation</i> | <i>Inclination of<br/>Equator to Orbit</i> | <i>Oblateness</i> | <i>Magnitude<br/>Brightest</i> |
|-------------|--------------------------------|------------------------------|------------------------------|-------------------------------|--------------------------------------------|-------------------|--------------------------------|
| Sun         | 864,000                        | 331,950                      | 1.41                         | 24d.65                        | 7°10'                                      | 0                 | -26.8                          |
| Moon        | 2,160                          | 0.012                        | 3.33                         | 27d.32                        | 6 41                                       | 0                 | -12.6                          |
| Mercury     | 2,900                          | 0.05                         | 6.1                          | 88d                           | 7 (?)                                      | 0                 | -1.9                           |
| Venus       | 7,600                          | 0.81                         | 5.06                         | 30 (?)                        | 23 (?)                                     | 0                 | -4.4                           |
| Earth       | 7,913                          | 1.00                         | 5.52                         | 23h 56m                       | 23 27                                      | 1/296             | .....                          |
| Mars        | 4,200                          | 0.11                         | 4.12                         | 24h 37m                       | 24                                         | 1/192             | -2.8                           |
| Jupiter     | 86,800                         | 318.4                        | 1.35                         | 9h 50m                        | 3 7                                        | 1/15              | -2.5                           |
| Saturn      | 71,500                         | 95.3                         | 0.71                         | 10h 02m                       | 26 45                                      | 1/9.5             | -0.4                           |
| Uranus      | 29,400                         | 14.5                         | 1.56                         | 10h 45m                       | 98                                         | 1/14              | +5.7                           |
| Neptune     | 28,000                         | 17.2                         | 2.29                         | 15h 48m                       | 29                                         | 1/40              | +7.6                           |
| Pluto       | 6,000 (?)                      | 0.83 (?)                     | ?                            | 6d (?)                        | ?                                          | ?                 | +12                            |

## SATELLITES OF THE SOLAR SYSTEM

| <i>Name</i>    | <i>Discovery</i> |      | <i>Mean distance in<br/>miles from planet</i> | <i>Period of<br/>Revolution</i> | <i>Diameter in<br/>Miles</i> |
|----------------|------------------|------|-----------------------------------------------|---------------------------------|------------------------------|
| <b>EARTH</b>   |                  |      |                                               |                                 |                              |
| Moon           |                  |      | 238,857                                       | 27d 7h 43m                      | 2,160                        |
| <b>MARS</b>    |                  |      |                                               |                                 |                              |
| Phobos         | Hall             | 1877 | 5,800                                         | 0d 7h 43m                       | 10(?)                        |
| Deimos         | Hall             | 1877 | 14,600                                        | 1d 6h 18m                       | 5(?)                         |
| <b>JUPITER</b> |                  |      |                                               |                                 |                              |
| V              | Barnard          | 1892 | 113,000                                       | 0d 11h 53m                      | 150(?)                       |
| Io             | Galileo          | 1610 | 262,000                                       | 1d 18h 28m                      | 2,000                        |
| Europa         | Galileo          | 1610 | 417,000                                       | 3d 13h 14m                      | 1,800                        |
| Ganymede       | Galileo          | 1610 | 666,000                                       | 7d 3h 43m                       | 3,100                        |
| Callisto       | Galileo          | 1610 | 1,170,000                                     | 16d 16h 32m                     | 2,800                        |
| VI             | Perrine          | 1904 | 7,120,000                                     | 250d 14h                        | 100(?)                       |
| VII            | Perrine          | 1905 | 7,290,000                                     | 259d 14h                        | 35(?)                        |
| X              | Nicholson        | 1938 | 7,300,000                                     | 260d 12h                        | 15(?)                        |
| XII            | Nicholson        | 1951 | 13,000,000                                    | 625d                            | 14(?)                        |
| XI             | Nicholson        | 1938 | 14,000,000                                    | 700d                            | 19(?)                        |
| VIII           | Melotte          | 1908 | 14,600,000                                    | 739d                            | 35(?)                        |
| IX             | Nicholson        | 1914 | 14,700,000                                    | 758d                            | 17(?)                        |

## SATELLITES OF THE SOLAR SYSTEM

| <i>Name</i> | <i>Discovery</i> |      | <i>Mean distance in<br/>miles from planet</i> | <i>Period of<br/>Revolution</i> | <i>Diameter in<br/>Miles</i> |
|-------------|------------------|------|-----------------------------------------------|---------------------------------|------------------------------|
| SATURN      |                  |      |                                               |                                 |                              |
| Mimas       | Herschel         | 1789 | 115,000                                       | 0d 22h 37m                      | 300(?)                       |
| Enceladus   | Herschel         | 1789 | 148,000                                       | 1d 8h 53m                       | 350                          |
| Tethys      | Cassini          | 1684 | 183,000                                       | 1d 21h 18m                      | 500                          |
| Dione       | Cassini          | 1684 | 234,000                                       | 2d 17h 41m                      | 500                          |
| Rhea        | Cassini          | 1672 | 327,000                                       | 4d 12h 25m                      | 1,000                        |
| Titan       | Huygens          | 1655 | 759,000                                       | 15d 22h 41m                     | 2,850                        |
| Hyperion    | Bond             | 1848 | 920,000                                       | 21d 6h 38m                      | 300(?)                       |
| Iapetus     | Cassini          | 1671 | 2,210,000                                     | 79d 7h 56m                      | 800                          |
| Phoebe      | Pickering        | 1898 | 8,034,000                                     | 550d                            | 200(?)                       |
| URANUS      |                  |      |                                               |                                 |                              |
| Miranda     | Kuiper           | 1948 | 81,000                                        | 1d 9h 56m                       | ?                            |
| Ariel       | Lassell          | 1851 | 119,000                                       | 2d 12h 29m                      | 600(?)                       |
| Umbriel     | Lassell          | 1851 | 166,000                                       | 4d 3h 28m                       | 400(?)                       |
| Titania     | Herschel         | 1787 | 272,000                                       | 8d 16h 56m                      | 1,000(?)                     |
| Oberon      | Herschel         | 1787 | 364,000                                       | 13d 11h 7m                      | 900(?)                       |
| NEPTUNE     |                  |      |                                               |                                 |                              |
| Triton      | Lassell          | 1846 | 220,000                                       | 5d 21h 3m                       | 2,350                        |
| Nereid      | Kuiper           | 1949 | 3,440,000                                     | 359d 10h                        | 200(?)                       |



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# **1001 Questions Answered About Astronomy**

**By James S. Pickering**

*Author of THE STARS ARE YOURS, etc.*

**MORE PEOPLE** than ever before are interested today in outer space and the countless worlds which inhabit it. Astronomy has become everybody's concern; the front pages of our newspapers and our television screens have taken over the secrets and wonders once reserved for scholars alone.

A member of the famous Hayden Planetarium has collected in a thousand key questions the universe around us — planets, satellites, meteors, comets, stars and constellations, galaxies, their origins, motions, distances, colors, methods and instruments of study, and every other conceivable fact and fiction that includes biographies of the great astronomers of all times.

This clearly printed volume contains sections and a detailed index for immediate reference to every conceivable astronomy topic.

**The author is Assistant Astronomer at the American Museum—Hayden Planetarium and is a member of many scientific societies, including the American Association of Variable Star Observers, the American Association for the Advancement of Science, etc.**

The book is generously illustrated with diagrams, line drawings and halftones.

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